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Development of a cost estimation process for human system integration practitioners during the analysis of alternatives

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THESIS

DEVELOPMENT OF A COST ESTIMATION PROCESS FOR HUMAN SYSTEM INTEGRATION PRACTITIONERS DURING THE ANALYSIS OF ALTERNATIVES

by

Deborah A. Sindall

December 2010

Thesis Advisor:	Lawrence G. Shattuck
Second Reader:	Daniel A. Nussbaum

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All too often, system requirements are not funded appropriately due to failure to incorporate Human Systems Integration (HSI) costs into the analysis of alternatives (AoA) in the acquisition process. Failure to incorporate HSI costs results in cost overruns and deficiencies in performance that have a significant impact on life-cycle costs. For a cost estimate to be accurate, all HSI domains (e.g., manpower, personnel, training, human factors) must be included. A thorough cost estimation process for an AoA should identify, justify, and estimate all HSI-specific activities. The current cost estimation processes are lacking these HSI-specific activities.

This thesis describes the initial development and evaluation of an HSI cost estimation process for use during the AoA. A database was created to capture all HSI-related activities during each phase of the acquisition process. Forty subject-matter experts (SMEs) reviewed and provided feedback on the database and on a list of HSI cost drivers. They also estimated the percent effort required for each HSI activity. SMEs concurred with 80% of the database and made valid recommendations for improving the remaining 20%. This initial framework represents a first step in providing a process for estimating the cost of HSI activities.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	Acquisition Category
AFI	Air Force Instruction
AoA	Analysis of Alternatives
AOTR	Assessment of Operational Test Readiness
APB	Acquisition Program Baseline
AS	Acquisition Strategy
ASR	Alternative System Review
AT&L	Acquisition Technology and Logistics
CAIG	Cost Analysis Independent Group
CARD	Cost Analysis Requirements Description
CBA	Capabilities-Based Assessment
CCA	Component Cost Analysis
CDD	Capability Development Document
CER	Cost element relationships
CES	Cost Element Structure
CJCSI	Chairman of the Joint Chief of Staff Instruction
CNO	Chief of Naval Operations
COMFLTFORCOMINST	Fleet Force Command Instruction
COMNAVAIRFORINST	Navy Air Systems Command Instruction
CONOPS	Concept of Operations
COSYSMO	Constructive Systems Engineering Cost Model
COTS	Commercial-off-the-Shelf
CPD	Capability Production Document
CPME	Collaborative Planning and Management Environment
CSR	Core Skill Requirements
DAB	Defense Acquisition Board
DAE	Defense Acquisition Executive

DAG	Defense Acquisition Guidebook
DAPS	Defense Acquisition Program Support
DAU	Defense Acquisition University
DCAPE	Director of Cost Assessment and Program Evaluation
DCR	DOTMLPF Change Recommendation
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities
DTC	Defense Technology Centre
DTM	Directive-Type Memorandum (DTM)
E&MD	Engineering and Manufacturing Development
ESOH	Environment, Safety, and Occupational Health
FAA	Federal Aviation Administration
FCA	Functional Configuration Audit
FMP	Fleet Modernization Program
FOC	Full Operational Capability
FRP&D	Full Rate Production and Deployment
FRPDR	Full Rate Production Decision Review (FRPDR)
GAO	Government Accountability Office
GE	General Electric
GSA	General Service Administration
HFE	Human Factors Engineering
HPW	Human Performance Wing
HSE	Human Systems Engineering
HSI	Human Systems Integration
ICD	Initial Capabilities Document
ICE	Independent Cost Estimate
IDAT&L	Integrated Defense Acquisition, Technology, and Logistics

IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
IPB	Initial Product Baseline
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team / Integrated Product Development Team
ISR	In-Service Review
ITR	Initial Technical Review
JCIDS	Joint Capabilities Integration and Development System
JROC	Joint Requirements Oversight Committee
KPP	Key Performance Parameter
KSA	Key System Attribute
LCCE	Life Cycle Cost Estimates
LCSP	Life Cycle Sustainment Plan
LFT&E	Live Fire Test and Evaluation
LRIP	Low Rate Initial Production
M&S	Modeling and Simulation
MAIS	Major Automated Information Systems
MANPRINT	Manual for Manpower and Personnel Integration
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Programs
MDD	Materiel Development Decision
META	MANPRINT Enterprise-tracking Analysis Tool
MSA	Materiel Solution Analysis
NAVAIR	Naval Air Systems Command
NAVPRINT	Navy Personnel Human System Integration
NAVSEA	Naval Sea Systems Command
NBCD	Nuclear Biological Chemical Defense
NEPA	National Environmental Policy Act
O&M	Operations and maintenance

O&S	Operation and Support
OCA	Office of Cost Assessment
OPNAV	Office of the Chief of Naval Operations
OPNAVINST	Office of the Chief of Naval Operations Instruction
ORM	Operational Risk Management
OSS&E	Operational Safety, Suitability, and Effectiveness
OTRR	Operational Test Readiness Review
OUSD	Office of the Undersecretary of Defense
P&D	Production and Deployment
P&R	Personnel and Readiness
PARS	Project Activity Reporting System
PBL	Performance-Based Logistics
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PEO	Program Executive Office
PESHE	Programmatic Environment, Safety and Occupational Health Evaluation
PM	Program Manager
POE	Program Office Estimate
PPBE	Planning, and Programming, Budget and Execution
PRR	Production Readiness Review
PSP	Product Support Plan
R&D	Research and Development
RAC	Risk Assessment Code
RDT&E	Research, Development, Testing and Evaluation
RFP	Request for Proposals
RM&S	Reliability, Maintainability and Sustainability
SCP	Service Cost Position
SECNAV	Secretary of the Navy
SECNAVINST	Secretary of the Navy Instruction

SEP	System Engineering Plan
SFR	System Functional Review
SME	Subject-matter experts
SPAWAR	Space and Naval Warfare Systems
SRR	System Requirement Review
SSEB	Source Selection Evaluation Board
SVR	System Verification Review
T&E	Test & Evaluation
TAD	Target Audience Description
TD	Technology Development
TDRA	Top Down Requirements Analysis
TDS	Technology Development Strategy
TEMP	Test and Evaluation Master Plan
TES	Test & Evaluation Strategy
TOC	Total Ownership Costs
TRR	Test Readiness Review
UAS	Unmanned Aerial System
USC	United States Code
WBS	Work Breakdown Structure
WSARA	Weapon System Reform Act

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EXECUTIVE SUMMARY

All too often, system requirements are not funded appropriately due to failure to incorporate Human Systems Integration (HSI) costs into the analysis of alternatives (AoA) in the acquisition process. Failure to incorporate HSI costs results in cost overruns and deficiencies in performance that have a significant impact on life-cycle costs. For a cost estimate to be accurate, all HSI domains (e.g., manpower, personnel, training, human factors) must be included. A thorough cost estimation process for an AoA should identify, justify, and estimate all HSI-specific activities.

This thesis describes the initial development and evaluation of the AoA HSI cost estimation process. The purpose of the HSI cost estimation process is to support budget development and justification over the life cycle of the system. The process presented in this thesis complements the management structures within the Integrated Defense Acquisition, Technology, and Logistics (IDAT&L) Life Cycle Management. By employing this process, HSI practitioners and other acquisition professionals will have access to information to support decision making throughout the life cycle of the system and to reduce total life cycle costs. This process was developed in conjunction with the HSI practitioners from the United States Air Force and Navy; however, it can be applied by all services and agencies within the Department of Defense and the federal government.

Two research efforts were carried out to evaluate the utility of the HSI cost estimation process. The first effort reviewed existing HSI instructions and guidance, and cost estimation methodologies. Information obtained from this research was used to design a database of specific HSI activities that require cost estimation during to the AoA. The second effort evaluated the content of the database for relevance and accuracy. The database was given to 83 U.S. Air Force and Navy subject-matter experts (SMEs) in the fields of HSI, defense acquisition and cost estimation; 40 responses were received. SMEs were generally satisfied with the database. They concurred with 80% of the database and made valid recommendations for improving the remaining 20%. The SMEs agreed that, once fully developed, the database would serve as a basis for a valuable HSI-specific cost estimation process that could support the HSI community during the AoA.

In order to improve the database, several SMEs recommended identifying the most important HSI activities in each of the oversight documents, including the following:

- Review Acquisition Strategy;
- Acquisition Plan;
- Source Selection Plan;
- Request For Proposal;
- Final Product Baseline;
- Critical Safety List Items;
- Programmatic Environment, Safety and Occupational Health Evaluation (PESHE); and,
- TEMP.

In addition, steps should be taken to clarify HSI activities in the Acquisition Management, Acquisition Engineering and Support/Sustainability activity tiers. Other recommendations included reorganizing the database in terms of work breakdown structure cost elements, identifying the benefits/impacts and risk/cost relationships of HSI activities.

Further development and evaluation of the database is required beyond what was completed for this thesis. These refinements include comparing HSI cost methods and developing the HSI variables that could be included in a cost model; determining the domain tradeoffs that must occur to achieve accurate cost estimates; and, using a system of interest in a case study to validate the database. The initial framework developed in this thesis represents a first step in providing a process for estimating the cost of HSI activities in the acquisition process.

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I. INTRODUCTION

A. BACKGROUND

Department of Defense (DoD) Instruction 5000.02 has directed Program Managers to take steps to include HSI considerations into their planning, development, design and execution of programs. This is necessary in order to minimize total ownership costs and also to optimize total system performance as early as possible in the acquisition process (Department of Defense, 2008c). In order to accomplish these tasks, line item costs from approved legacy system Work Breakdown Structures (WBS) are treated as baselines for component equipment (hardware, software, etc.) as well as manpower, then incorporated into the estimates for funded requirements. A formal cost estimation process for the components is also completed. All too often, requirements are not funded appropriately due to failure to incorporate HSI costs into the Analysis of Alternative process for various military system capabilities. These failures produce cost overruns and deficiencies in performance resulting in overall significant impact on the life-cycle cost. The development of a standardized HSI cost estimation model is needed. Such an HSI cost estimation model would fulfill the requirements of the system and define the system in terms of relevant activities specified by cost estimation relationships. The benefits and risks could reduce the impact on life-cycle cost. This model would provide program managers with an enhanced decision-making capability.

To provide appropriate measures, the methodologies need to encompass size or complexity drivers and life cycle phase involvement. The methodologies must be data-driven, with activity effort qualification and quantification. It is important to note that the approaches listed in this thesis are usually country or service specific. Current methodology for HSI estimates have been performed involving risk and benefit assessment, activity/cost factors and categorically defined approaches. An example of past cost avoidance methodology research includes a study completed by the Canadian organization Defence Technology Center (2006). This study provided five arguments with supporting case studies recommending Human Factors Integration (Canadian-termed HSI) inclusion into cost estimates. These estimates were included early in the acquisition process due to development or operational risk impact on programs. The specific arguments of the study encompassed reduction of cost (i.e., accident cost, redesign costs), technology development (i.e., complexity induced human error), identification and mitigation of operational risks (i.e., user involvement to ensure project success), resources (i.e., multiple benefit activities) and early involvement in project development to ensure success.

Research is currently ongoing to specify and define HSI activities and cost factors for research efforts by civilian and government agencies. A study by Liu, Rhodes and Valerdi (2009) investigated including HSI into the cost estimates. Liu et al. (2009) provided a case study of the Pratt & Whitney F119 engine, which powers the F-22 Raptor fighter aircraft. In this case, the Air Force, in response to the need to reduce life cycle cost, created the Reliability, Maintainability and Sustainability (RM&S) program in 1984. The RM&S program increased requirements for logistics and cost emphasis in the design of the F-22 engines. The push allowed for a competition in engine development by General Electric (GE) and Pratt & Whitney. GE chose improved F120 engine performance over using the RM&S standards. Pratt & Whitney surpassed GE by using integrated product development teams (IPT) with group involvement of seven out of nine domains of HSI (i.e., Survivability, Manpower, Personnel, Safety, Training, Human Factors Engineering and Occupational Health). The use of the IPTs allowed Pratt & Whitney to gain insight from different disciplines, as well as from the user population that affected their design decisions. This leads to an increased investment of time in the demonstration and internal efforts. Ultimately, HSI and other related testing increased 50% during the Engineering and Manufacturing Development (E&MD) phase. As a result of Pratt and Whitney's contribution of a management plan and development schedule, the Air Force awarded them the contract. Pratt and Whitney truly demonstrated an understanding of RM&S needs.

The Canadian Defence Technology Center conducted research from 2000 to 2004 on the application of HSI during 31 Defense acquisition programs providing cost to benefit analysis results savings of $3.33M. The methodology that the organization used to conduct the research was divided into three categories of HSI application based on five domains: Human Factor Engineering, Manpower, Personnel, Training, and combined System Safety and Health Hazard Assessment. The categories included the immediate saving of time and money that occurred during work effort, extrapolated savings (early HSI application produced saving money over time), and uncalculated savings (decisions resulting in saved lives or increased operational effectiveness). Each of these three measures provided definitive terminology and a dictionary of activities that when combined, provided savings across the life cycle of any program.

Kopardekar and Hewitt's (2002) concept paper for the Federal Aviation Administration discussed four methods of conducting human factor cost estimates involving committees, parametric methods (for human factor impact or type of study), and heuristic approaches. The study recommendations were based on percentage point system conversions for activities and complexity of HSI. At the time of completion, a recommended approach could not be specified, with the exception that the formation of committees for consistency of process estimation would be beneficial.

HSI domain cost methodologies are also scattered throughout such disciplines as Environmental, Safety and Health (EER System Inc, 1998). The cost analysis guides are predecessors of current HSI practices that can be updated for today's terminology and acquisition practices. Together, these applications can be modified with existing technology and methodology development. Together, these practices could help produce a general HSI system cost model and support the initiative to provide HSI costs early in the acquisition of systems.

1. Identification of HSI Domain Concentration in Life Cycle Phases

Each of the previous studies recommended further work to identify, quantify or qualify the activities of HSI within the life cycle phases. These HSI activities must be specified in order to provide sufficient cost relationships that will support cost estimation procedures. Examples of HSI-defined activities in life cycle phases are provided by the Defense Acquisition Integrated framework (Bahnmaier & Cochrane, 2009), Pacific Science and Engineering Group / Space and Naval Warfare Systems (SPAWAR) (Belk, Gepp, Risser, & Smillie, 2009), and Lindberg and Carr (2007). The Defense Acquisition Integrated Framework provides explicit definitions and procedural guidance throughout the life cycle phases. With this guidance, the Naval Postgraduate School has applied HSI specific activities for interactive teaching of the Acquisition life cycle that can be used for thesis development. These activities occur during each relevant phase in the life cycle. The Pacific Science and Engineering Group and SPAWAR have developed an integrated framework outlining the HSI activities and their interactions with each domain for every phase of the life cycle. Lindberg and Carr (2009) present activities by domain and phase that must be considered when training future HSI practitioners in Air Force Education and Training commands. These activities, the result of weapons system skill analysis, are relevant to cost estimates because task performance is based on the level of manpower effort (or fully burdened cost).

Other service-centric examples of activity assessments are also available. The Army's MANPRINT Enterprise-tracking Analyzer tool (META) provides activity-domain relationships for various programs by life cycle phase. In the life cycle phase, manpower effort level and time duration of HSI practitioners are available. The Air Force HSI Office developed an integrated tool similar to the DAU integrated framework (Booz Allen Hamilton Inc., 2009), one that aligns the HSI activities with the life cycle phase of DoD.

All of the processes listed above are in various stages of development and are specific to the armed service that funded the creation of the application. Currently, cost estimation functions have not been applied to the frameworks. These frameworks can contribute to a standard HSI domain activity-driven framework that is useful for work breakdown structure (WBS) element or Cost Element Structure (CES) development for cost estimation. Furthermore, each of these frameworks has yet to be compiled to form a standard process that has been adopted by DoD to pursue cost estimates.

2. Problem Statement

Given the aforementioned research and prototype applications currently under development, a standard cost estimation methodology for HSI -one that can easily be manipulated to fit the needs of any system still has not been developed.

The USAF's 711th Human Performance Wing (HPW) has taken on the task from the Office of Aerospace Studies of creating cost estimation tools for HSI. The 711th HPW began the task by considering HSI cost estimation practices during the AoA portion of the Defense acquisition process. For a cost estimate to be credible, a necessary condition is that it be comprehensive; i.e., all of the HSI domains (manpower, personnel, training, human factors, etc.) must be included. A formal process of cost estimation for an AoA should identify, justify and estimate all HSI-specific activities.

This cost estimation process for HSI activities should be coordinated with current USAF process stakeholders for Manpower, Personnel, Training, Environmental, Safety and Occupational Health. Furthermore, the estimation process should integrate all domains of HSI within services to the greatest extent possible, starting with the Capabilities-Based Assessment and continuing through Full Operational Capability. Prior to undertaking the development of a cost estimation methodology, an HSI Concept Model is needed to establish domain relationships within each of the four life-cycle phases (see Figure 1). This model correctly identifies those activities used by HSI practitioners. If a viable cost estimation methodology is developed, current Air Force programs, such as the unmanned aerial system (UAS) will benefit from results gathered during this thesis.

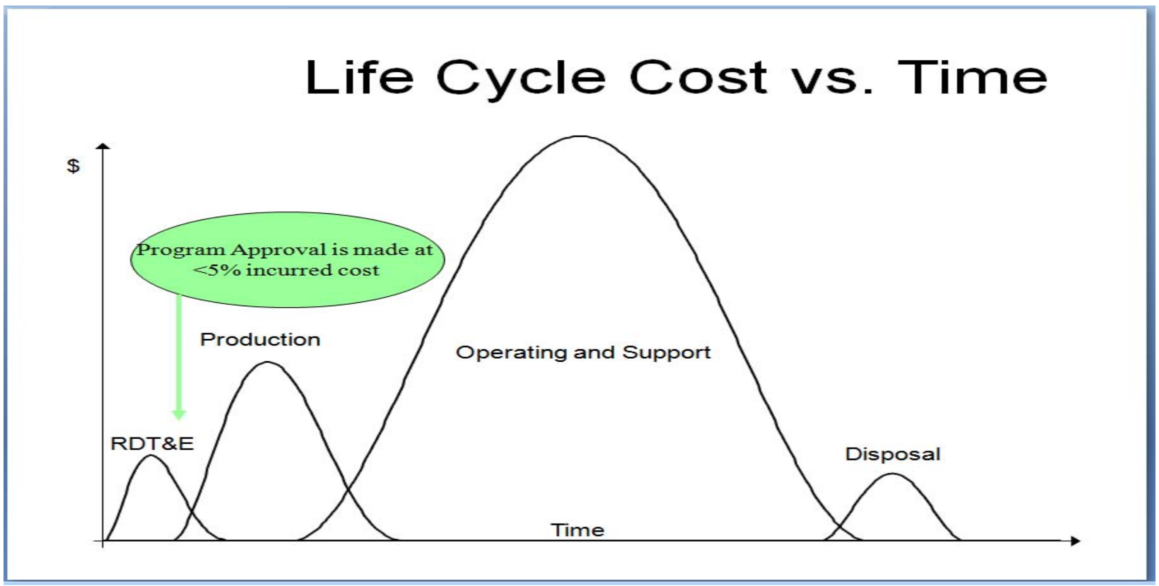

Figure 1. Life Cycle Cost (From Nussbaum, 2010)

3. Analysis of Alternatives Process

Chairman of the Joint Chief of Staff Instruction (CJCSI) 3170.01G, (2009) documents the general process for establishing life cycle costs during the AoA portion of the acquisition process. Capability gaps assessed in the JCIDS process allow for three courses of action:

- Accept the operational risk and perform no action.

- Seek doctrine change with a non-materiel approach.
- Provide a materiel solution.

Once the Initial Capabilities Document (ICD) documents the requirements for a materiel solution, the Milestone Decision Authority (MDA) determines the scope of the subsequent AoA production. Upon approval at the Milestone Development Decision (MDD), the AoA study is initiated and will guide the Materiel Solution Analysis phase. Further updates to the AoA occur at the Technology Development phase and at Milestone B as seen in Figure 2 (Defense Acquisition University, 2010. p. 95).

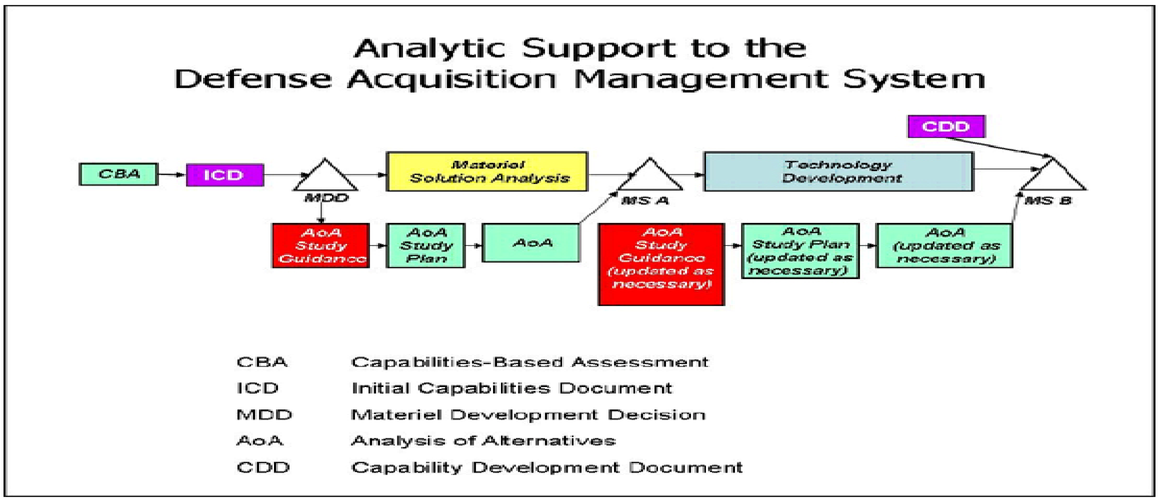

Figure 2. Analytic Support to the Defense Acquisition Management System (From Defense Acquisition University, 2010)

B. OBJECTIVES

- This thesis will give the USAF's 711th HPW a qualitative and quantitative view of HSI-specific cost criteria to conduct tradeoff considerations when making complex decisions within AoA.
- The thesis will benefit the AF HPW by developing a cost estimation method or process for the AoA. This method is essential for current

systems to support budget development and justification over the life cycle of system.

- By providing this method or process, HSI practitioners and other acquisition professionals will have improved information that should lead to better decisions. This process or method may also be useful for other services and agencies within the Department of Defense and the Federal government.
- The method or process will allow HSI practitioners and other professionals the capability to assess and mitigate potential risks and uncertainties that will influence the future development of systems.

C. RESEARCH QUESTIONS

- Where do HSI activities fall within the life cycle phases of DoD acquisition?
- What HSI cost estimation methodologies are currently used and why?
- What time durations or level of effort do HSI practitioners consider when performing HSI activities?
- What are the metric definitions used to determine cost factors of HSI activities?
- What levels of complexity must be considered when completing HSI cost estimates?
- What HSI costs are associated with AoAs?
- What HSI domain tradeoffs must occur to achieve comprehensive cost estimates with AoAs?

D. HSI CONSIDERATIONS

Manpower, Personnel, and Training are the domains most often considered when estimating cost. However, the domains of Human Factors Engineering, Environment, Safety, Occupational Health, Survivability, and Habitability will be also be addressed because they are also involved in tradeoffs and cost/ benefit analysis. If more cost factors are developed for AoAs, it should lead to the acquisition of systems that meet the needs of the Warfighter within the cost constraints imposed by the Federal budget.

The DoD Instruction 5000.02 Enclosure (8) and the DoD HSI Management Plan Enclosure (1) describe the variables of HSI that should be included by the program manager on various programs. To the extent possible, these variables should be integrated and receive tradeoff consideration in terms of the cost of the system or materiel solution used. The Air Force HSI Plan states that the activities of HSI must be defined and included in total life cycle cost. HSI activities should also be traceable and measurable (i.e., level of effort). These domain variables are subject to available data, and may not be inclusive:

> *Manpower*: In advance of contracting for operational support services, the PM shall work with the manpower community to determine the most efficient and cost-effective mix of DoD manpower and contract support. The mix of military, DoD civilian, and contract support necessary to operate, maintain, and support (to include providing training) the system shall be determined based on the Manpower Mix Criteria and reported in the Manpower Estimate. <u>Economic analyses</u> used to support workforce mix decisions shall use costing tools that account for <u>fully loaded costs</u>–i.e., all variable and fixed costs, compensation and non-compensation costs, current and deferred benefits, cash and in-kind benefits. (Department of Defense, 2008c, p. 60; Department of Defense, 2009b, p. 4)

> *Personnel*: To the extent possible, systems shall not require *special cognitive,* physical, or sensory skills beyond that found in the specified user population. For those programs that have skill requirements that exceed the knowledge, skills, and abilities of current military occupational specialties, or that require additional

skill indicators or hard-to-fill military occupational specialties, the PM shall consult with personnel communities to identify readiness, personnel tempo, and funding issues that impact program execution. The acquisition strategy and Life-Cycle Sustainment Plan should address modifications to the knowledge, skills, and abilities of military occupational specialties for system operators, maintainers, or support personnel if the modifications have cost or schedule issues that could adversely impact program execution. The program manager should consider personnel factors such as availability, recruitment, skill identifiers, promotion, and assignment. The program manager should consider the impact on recruiting, retention, promotions, and career progression when establishing program costs, and should assess these factors during trade-off analyses. (Department of Defense, 2008c, p. 60; Defense Acquisition University, 2010)

Training: The PM shall work with the training community to develop options for individual, collective, and joint training for operators, maintainers and support personnel, and, where appropriate, base training decisions on training effectiveness evaluations. The PM shall address the major elements of training, and place special emphasis on options that enhance user capabilities, maintain skill proficiencies, and reduce individual and collective training costs. The PM shall develop training system plans to maximize the use of new learning techniques, simulation technology, embedded training and distributed learning (DoD Instruction 1322.26 (Reference (be))), and instrumentation systems that provide "anytime, anyplace" training and reduce the demand on the training establishment. Where possible, the PM shall maximize the use of simulation-supported embedded training, and the training systems shall fully support and mirror the interoperability of the operational system. Identify training requirements and cost to maintain/refresh knowledge, skills, and abilities, and training or develop personnel attributes and training not currently available to the Navy. Conduct <u>affordability</u> assessments that include estimates of the TOC of the training infrastructure, manpower, and the training associated with each approach. (DoD Directive 1322.18 (Reference (bf); Department of Defense, 2008c, p. 61; Department of Defense, 2009b, p. 4)

Survivability: For systems with missions that might require exposure to combat threats, the PM shall address personnel survivability issues including protection against fratricide, detection, and instantaneous, cumulative, and residual nuclear, biological, and chemical effects; personnel survivability against asymmetric threats; the integrity of the crew compartment; and provisions for rapid egress when the system is severely damaged or destroyed. The PM shall address special equipment or gear needed to sustain crew operations in the operational environment, including the suitability of equipment intended to enhance personnel survivability against asymmetric threats. (Department of Defense, 2008c, p. 61)

Environmental, Safety and Occupational Health: The PM shall ensure that appropriate HSI and ESOH efforts are integrated across disciplines and into systems engineering to determine system design characteristics that can minimize the risks of acute or chronic illness, disability, or death or injury to operators and maintainers; and enhance job performance and productivity of the personnel who operate, maintain, or support the system. (Department of Defense, 2008c, p. 61) Costs can be associated with functions within legacy systems increasing accident rates or hazardous environments that predispose long-term medical related costs. Costs associated with concept development allowing for mitigation of safety and health issues (e.g. warning systems, enhanced safety procedures) will also be relevant.

Habitability: The PM shall work with habitability representatives to establish requirements for the physical environment (e.g., adequate space and temperature control) and, if appropriate, requirements for personnel services (e.g., medical and mess) and living conditions (e.g., berthing and personal hygiene) for conditions that have a direct impact on meeting or sustaining system performance or that have such an adverse impact on quality of life and morale that recruitment or retention is degraded. (Department of Defense, 2008c, p. 60)

Human Factors Engineering: Where practicable and cost effective, system designs shall minimize or eliminate system characteristics that require excessive cognitive, physical, or sensory skills; entail extensive training or workload-intensive tasks; result in mission-critical errors; or produce safety or health hazards. Identify MPT TOC savings achieved through analysis of design human factors, workload, and associated KSAs, resources, and tools for all tasks allocated to humans required for the efficient operation, employment, and support of the system. (Department of Defense, 2008c, p. 60; Department of Defense, 2009b, p. 3)

E. THESIS ORGANIZATION

Chapters pertaining to the development of the final product will organize this thesis. Chapter II reviews the literature that was used to develop and establish the cost estimation process. Chapter II will be broken into six parts.

Part One reviews the cost estimate decision support for thesis development. The section includes the statutory and regulatory basis for cost estimates, Department of Defense and life cycle management processes, Joint Capabilities Integration Development System (JCIDS) processes and HSI relevance within the acquisition life cycle. Part Two reviews cost estimation techniques, methods and processes to support thesis development. The section discusses the scope, estimate type purposes, rules and assumptions, and estimation techniques for this thesis. Further discussion will include modeling and identification of cost drivers as well as cost estimation methodologies to be in HSI effort determination. Part Three discusses the HSI Concept Model that will be used to develop our HSI cost estimation process. Part Four will discuss relevant cost estimation methods that are currently used for HSI cost estimation. Part Five will cover the system of interest for practical application, validation and verification of potential HSI cost estimation processes derived during thesis development.

Chapter III will discuss the method or processes to be used in the analysis of data. Chapter IV will cover the results of the analysis of data. Chapter V will discuss relevant lessons learned. Finally, Chapter VI will discuss the way forward.

II. LITERATURE REVIEW

The process of cost estimation goes beyond merely performing calculations for AoA or for congressional reports. Cost estimation is an amalgamation of support systems that helps ensure the validity, reproducibility and affordability of any defense acquisition program. As stated earlier, the AoA starts with Warfighter requirement determination. The requirements must meet the policy and strategy guidance, after which they must receive approval from Program, Budget and Execution processes before system capabilities can be produced. The focus of this chapter is to discuss these processes as well as the HSI activities that should be used for cost estimation. This chapter discusses the following:

- Cost estimation decision support system,
- Cost estimation methods,
- HSI concept models,
- Current HSI cost methods.

A. COST ESTIMATE DECISION SUPPORT SYSTEM

This section discusses the decision support system and HSI activity development in the Life Cycle Management system. Parts one through three discuss the decision support system including the Joint Capabilities Integration and Development System (JCIDS); Acquisition Management and the DoD Planning, and Programming, Budget and Execution (PPBE) process. Part four discuss HSI processes in defense acquisition that require funding and/or manpower support. These processes are used in the development of a cost estimation process for HSI activities.

1. Statutory and Regulatory Requirements for Cost Estimates

The requirement for cost estimation is found in the United States Code (USC) Title 10, Sections 2430 through and 2435. The USC states that a full life cycle cost must be reported for each major defense acquisition program. The Secretary of Defense cannot approve the life cycle cost unless an independent cost estimate (ICE) of the full life cycle of the program has been completed. The ICE must be conducted by entities other than the organization directly responsible for the program, regardless of fund source or management control (USC, 2006, pp. 1194–1199). USC (2006) section 2433a states that an Acquisition Category (ACAT) I program must have approval of the Director of Cost Assessment and Program Evaluation (DCAPE) in order to proceed to the Technology Development (TD), E&MD, and Production and Deployment (P&D) stages.

Key regulatory costing events or items are mandatory inputs to the milestone decisions that are made at the end of the TD, E&MD, and P&D stages. These events are as follows: Cost Analysis Requirements Description (CARD), Life Cycle Cost Estimates (LCCE) and, Service Cost Position (SCP) / Independent Cost Estimate (ICE) (See Figure 3).

The CARD provides a common technical description and a system baseline, as well as technical descriptions for all organizations providing cost projections (Nussbaum, 2010). The CARD is reviewed at each milestone. The next section discusses the LCCE and ICE cost events.

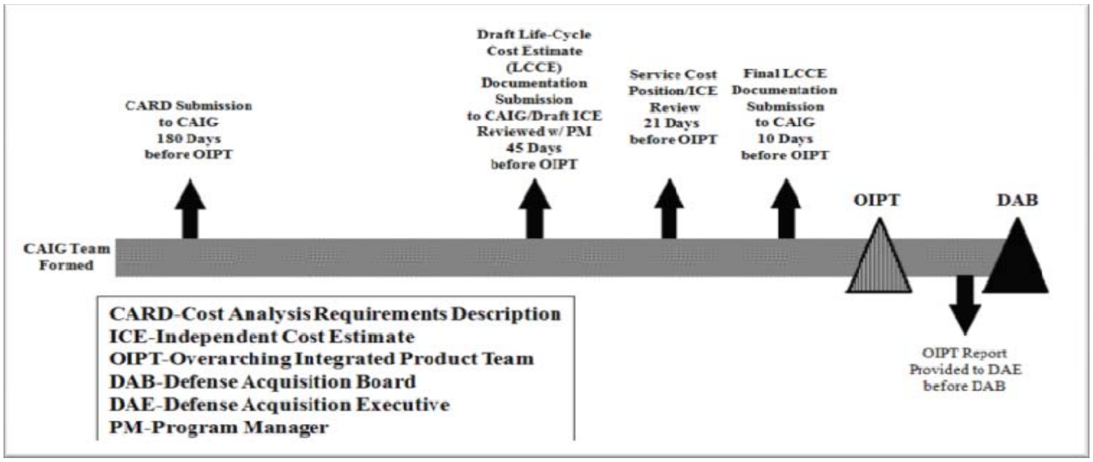

Figure 3. Key Regulatory Costing Events leading to a DAB Milestone Decision (From Nussbaum, 2010)

2. Department of Defense/Life Cycle Management Process

DoDI 5000.02 and DoD Directive 5000.04 provide further clarification for development of LCCE, ICE requirements for ACAT programs. Details for establishment of the Office of Cost Assessment (OCA) and Director of Cost Assessment and Program Evaluation (DCAPE) are also provided.

When a program is initiated, the service program office must produce a Program Office Estimate (POE). If ACAT ID programs involve significant risk or are considered highly visible, a Component Cost Analysis (CCA) will also be prepared. The Component Acquisition Executive requests the CCA. Specifically, DoDI 5000.02 states:

> For ACAT ID or ACAT IC programs, the independent cost estimate is required prior to certification at Milestone A (see 10 U.S.C. 2366a), Milestone B (see 10 U.S.C. 2366b), and before any decision to enter into low-rate initial production or full-rate production. Independent cost estimates are also required in advance of certification following critical cost growth in major defense programs (pursuant to 10 U.S.C. 2433a). In addition, the Office of Cost Assessment for an ACAT ID program may conduct an independent cost estimate at any other time as directed by either the DCAPE or the USD (AT&L). (Defense Acquisition University, 2010; Department of Defense, 2008c)

Although an ICE is not required for ACAT IA programs, the DoD 5000 series requires a CCA at Milestone B and whenever an Economic Analysis is requested by the Milestone Decision Authority (MDA). The CCA and Economic Analysis estimates are completed by the OSD Office of Cost Assessment staff or sponsoring DoD components. Furthermore, milestone and decision reviews require a POE. However, life cycle benefits and costs, which are subject to the program's integrated product team approval, are required for the ACAT IA POE (Department of Defense, 2008c).

DoDI 5000.02 indicates that all DoD components (Military Departments and Defense Agencies) prepare LCCEs in support of their acquisition programs. "A LCCE attempts to identify all the costs of an acquisition program, from its initiation through disposal of the resulting system at the end of its useful life and to properly phase, or spread, the costs for inclusion in budget submission documents" (Department of Defense, 2008c; Defense Acquisition University, 2010). To account for affordability, the LCCEs are used during the review process to ensure system affordability and to provide budgetary considerations for Congress. Integrated Product Teams (IPTs) and an Integrated Product and Process Development (IPPD) are typically employed to ensure LCCEs are completed accurately. LCCEs are used in the Planning, Program, Budgeting and Execution process (PBBE) which, in turn, is used for the funding requests that are sent to Congress.

The last regulatory action to discuss is the establishment of the Office of Cost Assessment (OCA) and the DCAPE. DoD Directive 5000.04 states that "the OSD OCA provides independent analysis and advice to DoD officials on matters of cost estimation and cost analysis for weapons acquisition programs, including matters of program life cycle cost. The DCAPE provides policies and procedures for the conduct of all DoD cost estimates. The DCAPE also issues guidance relating to the full consideration of life-cycle management and sustainability costs. In addition, the DCAPE reviews DoD Component cost estimates and cost analyses conducted in connection with Major Defense Acquisition Programs (MDAP) and Major Automated Information Systems (MAIS)" (Department of Defense, 2008b).

3. Joint Capabilities Integration Development System (JCIDS)

This section discusses the principles that underlie JCIDS. Implemented in 2002, the JCIDS process evolved because the requirements process was flawed. The three underlying principles of the JCIDS process include: (a) Determining the needs from a joint perspective, (b) describing those needs in terms of capabilities, and (c) overseeing the DoD functional portfolio by a flag officer. These principles lead to the identification of the capabilities needed rather than to a specific materiel solution (i.e., system function need versus system requirement). A joint perspective allows for system development instead of parallel development, which may produce duplicate costs. Finally, the process, overseen by a flag officer, allows the scope of the solution to meet joint service needs rather than narrow requirements suiting one function.

The JCIDS process was revised in 2009 to include a Capability Based Assessment (CBA). The revision removed the processes of Functional Area Analysis, Functional Needs Analysis and the Functional Solutions Analysis. As the entry point into the acquisition process, the CBA identifies gaps and provides recommendations for closing the gap. As stated in Chapter I, this process eventually leads to a DOTMLPF Change Recommendation (DCR) and/or an AoA for a materiel and/or non-materiel solution.

It is important to consider HSI early in order to mitigate total cost. HSI consideration begins during the CBA when HSI subject-matter experts provide input for activities that will eventually be inserted into the Initial Capabilities Document (ICD) and Capabilities Development Document (CDD) (See Figure 4, Simpkiss, 2009). A CBA should consider the full spectrum of solutions, including doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF). If the ICD recommends a materiel solution, an AoA study plan is created. HSI practitioners can contribute to any of these alternatives.

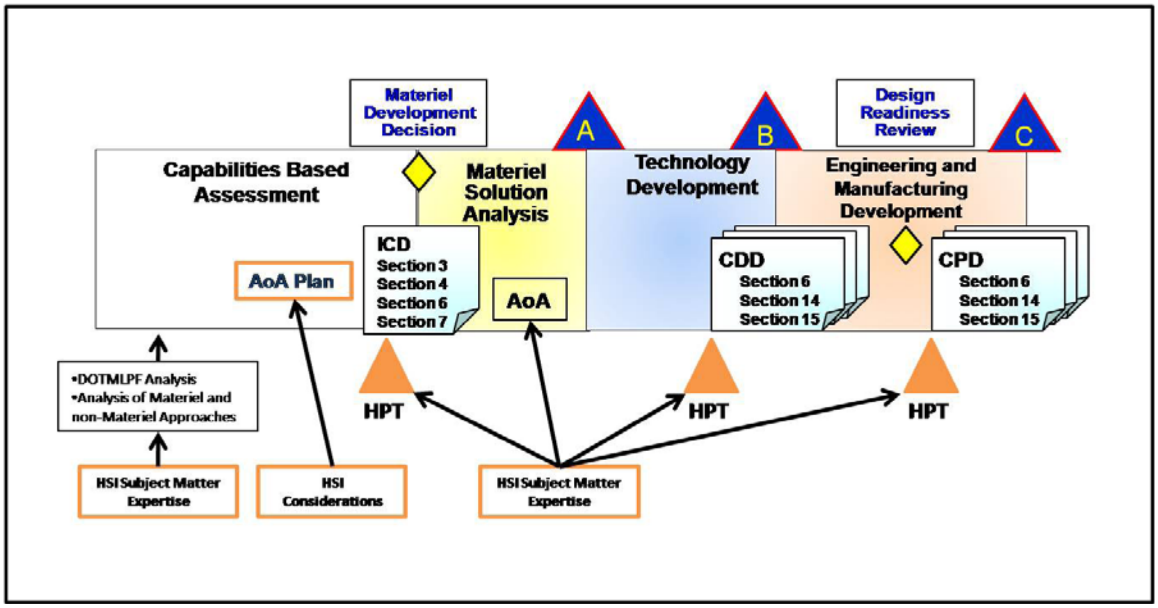

Figure 4. Human System Integration in Requirements (From Simpkiss, 2009)

Once the CBA has been completed, an ICD is written. Warfighter needs are identified in the JCIDS process and are developed into operational terms for the ICD. These operational terms are then molded into specific requirements in the CDD. The Joint Requirements Oversight Committee (JROC) and the Defense Acquisition Board (DAB) monitor and review the JCIDS activities throughout the acquisition life cycle.

The past three sections covered statutory and regulatory requirements for cost estimation, the Life Cycle Management Process and the Joint Capabilities Integration and Development System. The next section discusses the HSI activities that should be considered part of the cost estimation activities that occur in the acquisition process.

4. Human System Integration in the Acquisition Life Cycle

The Air Force HSI Requirements Pocket Guide (2009) and current service policies provide an excellent overview of the HSI activities in each phase of the acquisition life cycle. These documents will be used to explain the relevant HSI activities in each phase and their associated cost metrics. The Air Force Pocket Guide (2009) provides a detailed description of the HSI effort within the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System framework. These policies were chosen because of the abundance of use in the HSI community. Other policies exist such as MANPRINT (AR 602-2). The MANPRINT Handbook was review but did not add any additional insights to the present discussion.

Each military service has its own policies that mandate how HSI should be accomplished in the acquisition process. Four current service policies that are particularly informative are the (a) OPNAVINST 5310.23, *Navy Personnel Human System Integration (NAVPRINT)*, (b) Air Force Instruction (AFI) 10-601, *Capabilities Based Requirements Development,* (c) AFI 63-1201*, Life Cycle Systems Engineering* and (d) AFI 63-101, *Operations of Capability Based Acquisition Systems*.

OPNAVINST 5310.23D Enclosure (1) specifies that:

> The CBA must account for current and projected manpower and personnel characteristics. CBA analysis must identify operational or environmental conditions that may impact performance of the operators, maintainers and support personnel for future platforms and systems.
>
> The AoA provides the foundation for KPPs, key system attributes (KSA), and other attributes in CDDs and CPDs; therefore it is vitally important that HSI considerations, where applicable, be evaluated during the AoA. This allows HSI considerations (e.g., manpower and systems training) and their associated costs, to be addressed when selecting the preferred alternative. (Department of Defense, 2009e)

The Department of the Air Force Instruction, AFI 63-1201 emphasizes the incorporation of HSI into the System Engineering Plan (SEP) with specific guidance for Environment, Safety, Occupational Health and Habitability requirements. Specifically addressed are the Maintenance and Support personnel, who are the backbone of any operation. The document states: “It must be addressed throughout the life cycle, and must be consistently integrated into SE implementation to balance total system performance (hardware, software, and human), assurance of Operational Safety, Suitability, and Effectiveness (OSS&E), survivability, and affordability” (Department of Defense, 2007a).

Air Force Instruction 63-101 (2009) states that “the HSI office will oversee and advocate an HSI focus in activities regarding systems integration, systems engineering, total system performance and total operating costs” (pg. 41). This instruction highlights the system engineering process by stating: “ESOH integration strategy must define HSI roles and activities for those domains” (Department of Defense, 2009a). Emphasizing trade-offs between HSI domains, the ESOH integration strategy incorporates survivability of the system. In accordance with these instructions, the survivability of the system should be considered during trade-off analysis when considering affordability, schedule, and performance capabilities.

Clearly, an HSI focus is mandatory for Navy and Air Force acquisition programs. The next step is to examine the HSI activities that occur during each phase of the acquisition process and to consider the cost associated with these activities.

a. Materiel Solution Analysis (MSA) Phase

> The focus of the MSA phase is ‘completing Analysis of Alternatives to assess potential materiel solutions to capability need, identifying key technologies and estimate life cycle costs’. This phase ‘considers commercial-off-the-shelf solutions from both large and small business and identifies materiel solution to capability need’. (Defense Acquisition University Online, 2010)

The overall goal of the MSA phase is to identify an affordable, operationally effective materiel solution. During this phase, inputs are provided for MDA cost estimates, AoA study plan/analysis, study contracts, Technology Development Strategy (TDS), Request for Proposals (RFP) and draft CDD (Department of Defense, 2008c). The cost estimates given during this phase allow the MDA to determine adequate funding of the Technology Development Phase for the preferred materiel solution. In this section, relevant HSI activities are described from current resources including: (a) SECNAV-5000.2 *Navy Acquisition and Capabilities Guidebook,* (b) Defense Acquisition Guidebook, (c) DoD 5000 series instruction, (d) 2010 Weapon System Reform Act (WSARA) and the (e) Human Systems Engineering Manual.

SECNAVM-5000.2 states the importance of HSI activities within the Technology Development Strategy (TDS) (See Figure 5). The TDS includes: (a) Determining issues related to physical/mental characteristics, (b) describing the target audience description (TAD), and (c) providing performance parameters for operators and maintainers. When determining affordability, feasibility, and risk, HSI practitioners must also consider training, manpower, job specialization (Personnel Rates/MOS), and technology insertion (DoD [2008d]; Enclosure 7).

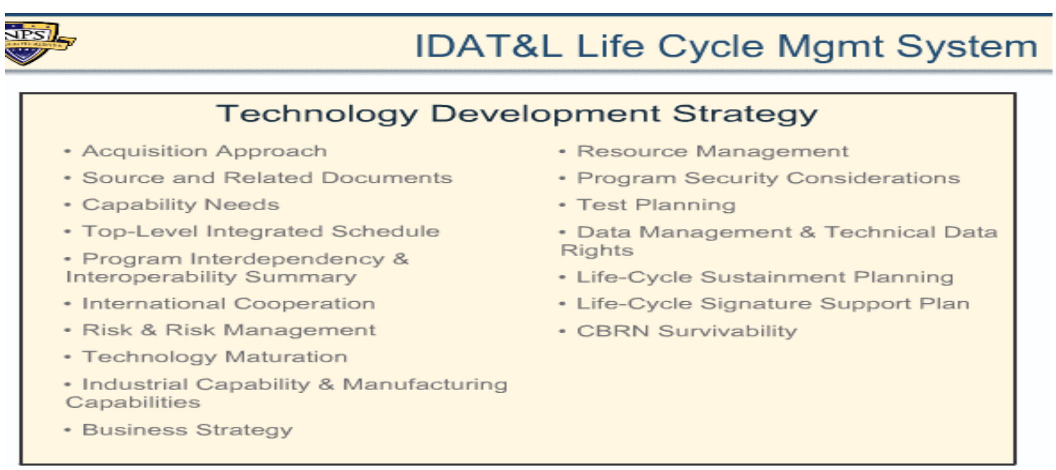

Figure 5. Technology Development Strategy Contents (From Defense Acquisition University, 2010)

The second resource is the Defense Acquisition Guidebook (DAG), Chapter 3. The DAG describes the AoA process and begins with a detailed structure of the AoA Study Plan. Included in the plan are analysis for scenario and threat development (bound by physical and environmental constraints). Capability ranges are also used to determine testing scenarios, while operation effectiveness measures are used to associate metrics for military worth with the alternatives (i.e., mission outcome, system performance, identification of simulation models).

Life-cycle cost analysis will be a part of the study plan. The life cycle cost estimate is combined with the operational effectiveness analysis for a full cost-effectiveness comparison portrayal (see Figure 6). The final segment of the AoA Study Plan includes the organization and management structure for conducting the AoA, as well as any oversight and guidance needed. With the AoA Study Plan in place, the AoA can proceed as described in the next paragraph.

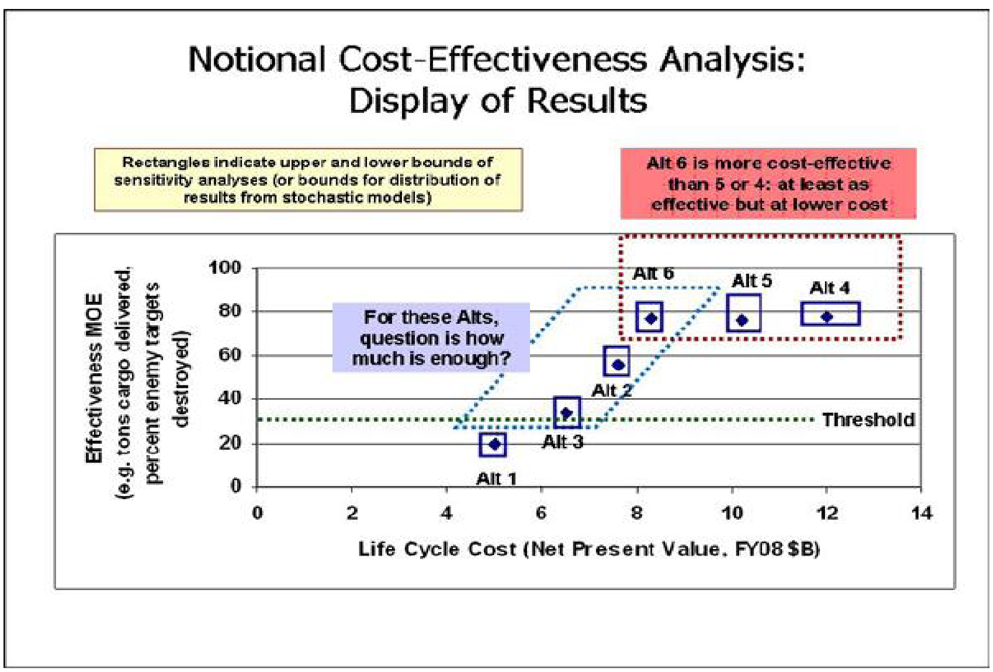

Figure 6. Sample Scatter Plot of Effectiveness versus Cost comparison (From Defense Acquisition University, 2010)

The HSI activities for the AoA process are distributed throughout DoD 5000 series instructions. Possible AoA materiel solutions are based on the ability for system alternatives to meet/fulfill concepts of operation, measures of effectiveness, cost, schedule, and risk criteria for technologies. Commercial-off-the-Shelf (COTS) solutions are used if possible. DoDI 5000.02 directs that “the AoA shall assess the critical technology elements associated with each proposed materiel solution, including technology maturity, integration risk, manufacturing feasibility, and, where necessary, technology maturation, and demonstration needs” (Department of Defense, 2008c).

The 2010 Weapons System Acquisition Reform Act (WSARA) explicitly amends DoDI 5000.02 and the Defense Federal Acquisition Regulation Supplement to require competition for prototype development. Fox (2010) stated that the 2010 WSARA will help:

- Identify cost risk earlier,
- Baseline programs with realistic cost and schedule estimates,
- Ensure rigors of AoA,
- Ensure Departments fully fund development and procurement cost of programs, and
- Lead Departments in improving cost assessment and analysis.

The implementation of the 2010 WSARA affects performance assessments of an AoA by requiring that all acquisition programs:

> Evaluate the cost, schedule, and performance of the program, relative to current metrics, performance requirements, and baseline parameters, and determine the extent to which the level of program cost, schedule, and performance, relative to established metrics, is likely to result in the timely delivery of a level of capability to the Warfighter that is consistent with the level of resources to be expended and to provide superior value to alternative approaches that may be available to meet the same requirement. (Hansen, 2010)

In performing AoA studies, the Navy and Air Force identify trade-off analysis as a key factor for HSI involvement. The Navy Acquisition gate process (Whitaker, 2009) (See Figure 7) identifies capability gaps and applies acceptable operational thresholds and objectives when conducting the trade-off studies. At the Gate 2 review, analysis of DOTMLPF must occur. The HSI practitioner can contribute by assessing tradeoffs among HSI domains and providing specific cost adjustments to mitigate cost overruns. Practitioners also identify capability gaps to provide input for rough order of magnitude cost assessment as specified in OPNAV Instruction 5310.23. Capability gap contributions and/or limitations may include:

- Manpower, personnel, or training (including military, contractor, civilian and recruitment/retention of each),
- Contributions of operator, maintainer, support personnel, total system performance (including infrastructure),
- Requirements for safety, survivability, habitability, and
- System reliability, maintainability, transportability, and supportability

A goal of capability gap identification is the reduction of the system's logistics footprint and total ownership cost (Shattuck, 2010).

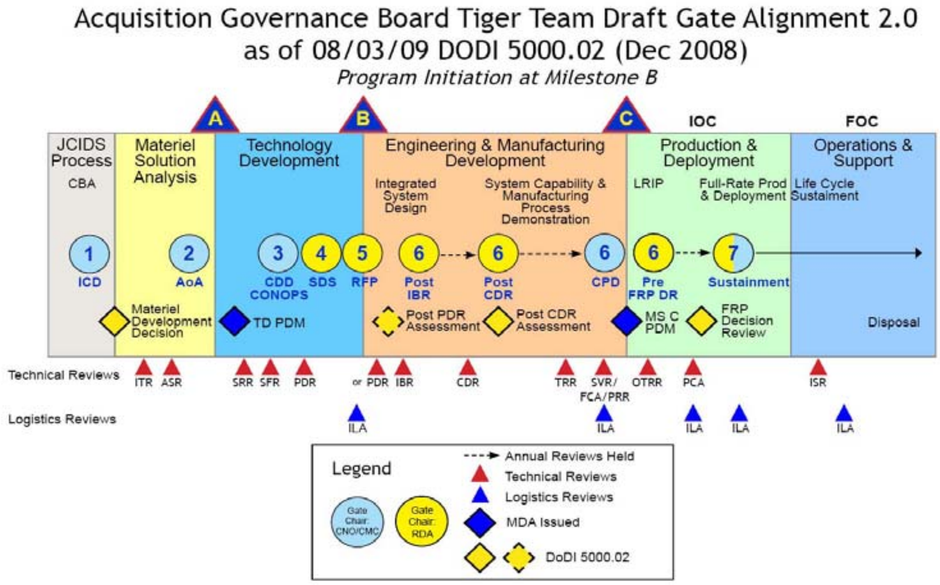

Figure 7. Navy Gate Alignment Dec 2008 (From Whitaker, 2009)

The aforementioned gap analyses are an important exit criteria for the materiel solution analysis phase and are assessed at Milestone A prior to the development of the system. Furthermore, the use of the capabilities assessments will allow comparisons with benchmark resources (current system capabilities and costs) and future developments in AoA.

The Human System Engineering (HSE) Manual provides further guidance for HSI activities and cost considerations during the MSA phase. Insights into potential COTS materiel solution approaches and HSI domain trade-space analysis are specified. The HSE Manual states:

> The COTS approach has (a) the lowest projected life cycle cost, within acceptable risks, and meets essential requirements, including human performance requirements; (b) the lowest human workload and manning requirements for operations and maintenance; (c) the most effective training program; and (d) the least safety and health hazards. (Naval Sea Systems Command, 2009, p. 29)

Domain trade-offs include optimizing manpower, addressing training requirements, incorporating safety, and designing for survivability. In conducting trade-offs, manpower can be optimized by including the proper mix of personnel, conducting a workload analysis, reviewing policy, and increasing performer effectiveness. Training requirements for specific designs are also considered. Risk reduction and hazard prevention in system design must consider safety and health concerns. In trade-off studies, the personnel survivability equipment design is an essential consideration. Increased performance and maintenance requirements are used to research and test equipment design. The Life Cycle Sustainment Plan (LCSP) also recognizes these domain initiatives. The LCSP considers the domain trade-offs as contributing factors to the reduction of total operating costs.

Finally, habitability requirements for personnel are considered, but generally are the least found in trade-off studies. Habitability trade-offs may include design of living conditions that would impact working conditions and quality of life. Thus far, section (a) has considered HSI activity development and trade-off studies in the MSA phase. The next step concerns the technical review process that ensures performance and funding requirements are met.

The MSA phase includes two technical review processes to ensure programs meet performance and funding requirements. These technical reviews are the Initial Technical Review (ITR) and the Alternative System Review (ASR). The ITR ensures cost estimate validity, assesses capability needs and materiel solutions, and identifies cost drivers. As stated in the NAVSEA HSE manual, the ITR process may include HSI assessments based on mission scenario functions allocated by the Navy Tactical Task list. By doing so, performance metrics are identified and thus, drivers (i.e., manpower effort) for cost relationships are established. ITR scenarios may also identify training requirements imposed by system operation.

The ASR, on the other hand, ensures that the system is ready to move on to the Technology Development phase and meets the requirements set by the user. The ASR will provide a review of the AoA and provide a comprehensive rationale for the proposed solution (Shattuck, 2010). By reviewing alternative materiel solutions, the ASR helps:

> … ensure that sufficient effort has been given to conducting trade studies that consider and incorporate alternative system designs that may more effectively and efficiently meet the defined capabilities. (DAU Online, 2010)

The HSI practitioner aids in this process by being involved in the Integrated Product Team and by providing input for workload and manpower requirements for each alternative. By doing so, performance effectiveness, training assessments, system interoperability, test and evaluation (T&E) and life cycle costs (including schedule, cost, and performance trade-offs) for each alternative reflects actual costs more accurately.

The Materiel Solution Analysis phase ends when the exit criteria are met, including:

- Initial acquisition strategy (including the sustainment strategy),
- Contractual documents required to continue into the Technology Development Phase,
- Initial support and maintenance concepts,
- Life cycle costs, and
- Manpower estimates for the system concept.

Finally, input is provided for the draft CDD and the Test & Evaluation Strategy (TES). The TES must include estimated costs pertaining to system operation and system attributes. HSI analysis will be included in the TES and must be included in cost estimates.

Section (a) provided an overview of HSI activities in the Materiel Solution Analysis phase. See Table 1 for a summary of HSI activities during the MSA phase. HSI manpower effort and/or HSI funding requirements were established. Section (b) will provide an overview of the same issues for the Technology Development phase.

Table 1. MSA Phase HSI Activity Summary

HSI Activity	Publication	IDAT&L Activity
1. Determine issues related to physical/mental characteristics.	SECNAVM-5000.2	Technology Development Strategy (TDS)
2. Describe the target audience description (TAD).	SECNAVM-5000.2	TDS
3. Provide performance parameters for operators and maintainers.	SECNAVM-5000.2	TDS
4. Assess affordability, feasibility and risk. Consider training, manpower, job specialization (Personnel Rates/MOS), and technology insertion (Enclosure 7).	SECNAVM-5000.2	TDS
5. Conduct scenario and threat development analysis as well as capability ranges.	Defense Acquisition Guidebook	AoA Study Plan
6. Assess the critical technology elements.	DoD 5000 Series	AoA
7. Review DOTMLPF. 8. Conduct trade-off analysis of among HSI domains and provide specific cost adjustments to mitigate cost overruns.	2010 WSARA	AoA
9. Identify capability gaps to provide input for rough order of magnitude cost assessment.	OPNAV Instruction 5310.23	AoA
10. Conduct a COTs HSI domain trade-space analysis.	HSE Manual	AoA
11. Review HSI mission scenario assessments, metrics, training requirements	HSE Manual	Initial Technical Review (ITR)
12. Participate in Integrated Product Team; Provide input for workload and manpower requirements for each alternative.	Shattuck, 2009	Alternative System Review (ASR)
13. Provide input for draft CDD and the Test and Evaluation Strategy (TES) pertaining to system operation and system attributes.	Shattuck, 2009	Alternative System Review (ASR)

b. Technology Development Phase

> The focus of this phase is ‘to reduce technology risk and to determine the appropriate set of technologies to be integrated into the full system. This effort is normally funded only for advanced development work and does not mean that a new acquisition program has been initiated’. (DAU Online, 2010)

DoDI 5000.02 and the JCIDS Manual (2009) state the overall goal of the Technology Development (TD) phase is to reduce risk and determine the maturity of systems for full system integration and prototype development. The TD phase contributes to continuous technology discovery and successful collaboration between the user, the S&T community, and the system developer. Viability of technologies and refining user requirements is of utmost importance. During this phase, inputs are required for the following documents and activities:

- Capability Development Document (CDD),
- Acquisition Strategy (AS),
- Acquisition Program Baseline (APB),
- System Engineering Plan (SEP),
- Test and Evaluation Master Plan (TEMP),
- Request for Proposal (RFP),
- System Performance Specifications, and
- Technical Reviews

In this section, the following resources will be used to describe the TD phase HSI activities:

- DoD 5000 series instruction,
- JCIDS Manual,
- OPNAVINST 5310.23,

- 711th Human Performance Wing Human System Integration Development (HPW HSI) Guide,
- Human Systems Engineering (HSE) Manual, and
- Secretary of the Navy (SECNAV) guidance

HSI practitioner involvement in the TD phase begins with the development of the Capability Development Document (CDD). DoDI 5000.02 states that every acquisition program or evolutionary increment requires a CDD. The CDD shall refine integrated architecture as well as clarify how the program will lead to joint warfighting capability. Additionally, the JCIDS Manual states that the CDD must address the system capabilities and key performance parameters (KPPs) of the system. HSI issues that affect the suitability, affordability and effectiveness of the system are also addressed (Department of Defense, 2008c). The JCIDS manual specifies that design considerations must consider environmental factors, unplanned stimuli and mission capability. Mission capability is extremely important especially in nuclear, biological, chemical, and environments.

OPNAVINST 5310.23 describes the HSI-related capabilities that should be discussed in the CDD. The KPPs should include threshold and objective values that ensure Warfighters are able to achieve required levels of performance. The 711th HPW HSI Guide and HSE Manual address the human-centered KPPs and capabilities that should be considered in system design.

HSI practitioners also provide input into the Acquisition Strategy (AS) and Acquisition Program Baselines (APBs). HSI input (as part of an IPT) is governed by SECNAV guidance and service policies. SECNAVINST 5000.2D indicates:

> Life cycle cost projections for capabilities and/or systems shall include direct HSI costs (e.g., MPT), and should discuss indirect costs (e.g., medical benefits resulting from safety and occupational health risks)…HSI issues and domains must be considered to

ensure that configuration changes do not create new or unforeseen HSI issues. (Department of Defense, 2008d, p. 12)

Milestone B approval is dependent on the Acquisition Strategy which will incorporate development, testing, production and life cycle support as critical elements.

APBs are a necessary step in establishing the trade-offs between cost, schedule and performance. Many of the KPP, KSA, threshold/objective values, and requirements are human performance based, which affect system performance. Within the APB, operationally determined performance parameters, measures of effectiveness, and performance help to determine drivers cost estimates. The APB consists of the following components (see Table 2):

Table 2. APB Cost Involvement (From Shattuck, 2009)

Research, development, test and evaluation costs	Operations and maintenance (O&M) costs
Procurement costs	Average Procurement Unit
Military construction costs	Program Acquisition Unit Cost
Total system quality	Any other cost objectives established by the milestone Decision Authority

The APB is approved by the MDA and must concur with the Program Executive Officer (PEO) for all ACAT programs, and the DoD Component Acquisition Executive (CAE) for ACAT ID and IAM programs (Shattuck, 2009).

The HSE Manual describes the application of HSI initiatives in the Acquisition Strategy, System Engineering Plan, Test and Evaluation Master Plan and Request for Proposal. To fulfill the HSI objectives of the system, the manual incorporates the following:

- Human performance,
- Workload,
- Safety issues,

- Risk assessments, and
- Reduction in technology applications

HSI practitioners also provide input on human techniques, system interactions (i.e., software, hardware) and HSI metrics. The activities will emphasize “mission capability, readiness, force structure, affordability, performance effectiveness, and achievement of wartime operational objectives” (NAVSEA, 2009, pp. 6–51). By doing so, HSI needs and requirements are successfully included in technology contracts and prototype RFPs.

A major output of the TD phase is the system performance specifications. HSI practitioners provide input to the program manager to help determine trade-offs for cost, schedule and performance. The HSE Manual addresses performance specifications by identifying human roles and responsibilities. The manual includes “Requirements for sustained human performance...prevention of human error…approaches that reduce human error and cognitive workload and human machine interface designs that facilitate human performance” (Shattuck, 2009, p.4; NAVSEA, 2009, pp.6–55).

Finally, three major reviews occur in the TD phase. These reviews are the System Requirement Review (SRR), System Functional Review (SFR) and the Preliminary Design Review (PDR). HSI input into each of these reviews allows for the mitigation of potential shortfalls and the survivability of the system in future operational testing, evaluation and verification events.

The SRR specifies the allocation of tasks to the human, software, and hardware in the system. The SFR includes operational level functional requirements for the various subsystems. The review also allows for assignment of those requirements to operations, maintenance and sustainment considerations. IPTs can then initiate preliminary design.

The PDR establishes a “physically allocated baseline” that helps determine the level of operational effectiveness that the system will demonstrate

(Shattuck, 2009). The PDR ensures design configuration and capabilities are in accordance with cost, schedule, and performance requirements. The PDR may be completed in the Engineering and Manufacturing Development (E&MD) phase. The TD phase ends at Milestone B and at the completion of the preliminary design.

Section (b) provided an overview of HSI activities in the Technology Development phase. Table 3 provides a summary of the HSI activities during the TD phase. Section (c) will provide an overview of the same issues for the Engineering and Manufacturing Development phase.

Table 3. TD Phase HSI Activity Summary

HSI Activity	Publication	IDAT&L Activity
1. Address the system capabilities and key performance parameters (KPPs). 2. Assess the suitability, affordability and effectiveness of the system (consider environmental factors, unplanned stimuli and mission capability).	DoDI 5000.02; JCIDS Manual; OPNAVINST 5310.23; 711th HPW HSI Guide and HSE Manual	Capability Development Document (CDD),
3. Life cycle cost projections for capabilities and/or systems shall include direct HSI cost. 4. HSI issues and domains must be considered to ensure that configuration changes do not create new or unforeseen HSI issues.	SECNAVINST 5000.2D; service policies	Acquisition Strategy (AS),
5. Assess KPP, KSA, threshold/objective values, and requirements for trade-off analysis.	SECNAVINST 5000.2D; service policies	Acquisition Program Baseline (APB),
6. Assess system for human performance, workload, safety issues, risk assessments, and reduction in technology applications. 7. Provide input on human techniques, system interactions (i.e., software, hardware) and HSI metrics.	HSE Manual	System Engineering Plan (SEP), Test and Evaluation Master Plan (TEMP), and
8. Assess HSI needs and requirements in the technology contracts.	HSE Manual	Request for Proposal (RFP).
9. Provide input to the PM to determine trade-offs for cost, schedule and performance.	HSE Manual	System performance specifications
10. Provide input into the technical reviews for mitigation of potential shortfalls and the survivability of the system in future operational testing, evaluation and verification events.	HSE Manual	System Requirement Review (SRR), System Functional Review (SFR) and the Preliminary Design Review (PDR).

c. Engineering and Manufacturing Development Phase

> The purpose of the E&MD Phase is to develop a system or an increment of capability; complete full system integration; develop an affordable and executable manufacturing process; ensure operational supportability with particular attention to minimizing the logistics footprint; implement human systems integration (HSI); design for producibility and ensure affordability; protect CPI by implementing appropriate techniques such as anti-tamper; and demonstrate system integration, interoperability, safety, and utility. (DAU Online, 2010)

The Engineering and Manufacturing (E&MD) phase consists of two efforts: the Integrated System Design (ISD) and the System Capability and Manufacturing Process Demonstration (SC&MPD). The E&MD phase begins after a successful Milestone B review and includes a Post Critical Design Review (CDR) Assessment at the end of the ISD. The Post-CDR Assessment will confirm design maturity and provide the initial product baseline. The following P&D phase documents guide the E&MD phase:

- Capability Development Document,
- Acquisition Strategy,
- System Engineering Plan, and
- Test Evaluation Master Plan (TEMP)

The SC&MPD effort, completed after the Post-Critical Design Review, shall demonstrate the operation of the systems (with the approved KPPs) in the intended environment of use.

The E&MD phase contains six embedded processes (i.e., JCIDS, Oversight and review, Contracting, Major Products, Logistics/ Sustainment and Technical). HSI practitioners are not directly involved in production and manufacturing activities; however, practitioners do monitor the activities to reduce risk. The initial phase activity includes MDA updates to the Acquisition Strategy and APB administrative review processes that should contain HSI input.

This Input ensures that a defense acquisition program continues to have an HSI emphasis and that program managers will be able to maintain planned schedules. HSI considerations are important as the E&MD continues with the Source Selection Evaluation Board (SSEB). HSI board members will review RFPs for HSI concerns. A majority of HSI involvement occurs during prototype development.

In prototype development, HSI practitioners help to build and use the models and simulation tools for testing purposes. By doing so, human performance modeling allows mitigation of risk and safety issues that can occur early in the system development. Further HSI activities revolve around the Product Support Plan (PSP) and the Performance-Based Logistics (PBL) Strategy. These activities focus on several HSI domains: Manpower, Training, Personnel, HFE and Habitability. Because the system may change operationally, by mission capability, or by change in organization and/or funding, the logistician must update the PSP repeatedly. Therefore, HSI practitioners are continuously required to provide input. The DoDI 5000.02, DAG (2010) and Shattuck (2009) state that these inputs to include:

- Reduction of time in maintenance and / or operation due to HFE influenced design,
- Requirement development during Personnel Selection (i.e., knowledge, skills, attribute, and experience levels),
- Manpower reduction or increase use of the proper mix of military, contract, civilian workers,
- Training development, test evaluation and verification,
- Habitability concerns such as “morale, safety, health, comfort, personnel performance, or unit readiness, that could lead to recruitment or retention problems” (Shattuck, 2009), and

- Environment, Safety and Operational Health concerns such as mitigation of health deterioration or mishaps due to system design and human centered environmental designs.

While habitability is important in design considerations, the domain criteria usually fall under other guidance. References to publications that guide habitability design efforts include: (a) the Naval Sea Systems Command (2006) *Joint Fleet Maintenance Manual* (COMFLTFORCOMINST 4790.3), and (b) the Air Force Air Force Habitability and Occupational Health publications. These publications are service and/or system specific and refer to the following guidance:

- OPNAVINST 9640.1, Shipboard Habitability Program,
- NAVSEA SL720-AA-MAN-010/V1R2. *Fleet Modernization Program (FMP) Management And Operations Manual*
- NAVSEA SL720-AA-MAN-030, Surface Ship and Carriers Entitled Process for Modernization Management and Operations Manual
- Air Force Policy Directive 23-1 (2009), Materiel Management Policies and Procedures,
- Air Force Policy Directive 21-1 (2003), Air and Space Maintenance,
- Air Force Occupational Safety And Health Standard 48-20 (2006), Occupational Noise And Hearing Conservation Program,
- Air Force Handbook 21-130, Technical Analysis To Determine Criterion For 2 Vs 3 Level Repair,
- Air Force Occupational Safety And Health Standard 48-139 (1999), Laser Radiation Protection Program,
- Air Force Pamphlet 90-902 (2000), Operational Risk Management (ORM) Guidelines And Tools,
- Preliminary Hazard Analysis, Hazard Listing, Risk Assessment, and

- Air Force Instruction 90-1301(2008), Implementing Military Flight Operations Quality Assurance.

The CPD is one of the final documents produced during the E&MD phase. The CPD helps to determine the operational performance parameters. The CPD is revised as lessons are learned during system development and as KPPs and KSAs are refined. The ICD, CDD, AoA, CDR, development and operational testing, DoD Enterprise Architecture, and DOTMLPF recommendations also influence the CPD. Once approved by the JROC for operational acceptance, the MDA can initiate Milestone C and approve entry into the Production and Deployment (P&D) phase.

Military service guidance for incorporating HSI requirements into the CPD include the (a) Navy OPNAVINST 5310.23, (b) Air Force 711th HSI Development Guide, and the (c) Army MANPRINT documents. Examples of HSI requirement activities include:

- Identify the integrated training system requirements for individual, collective, joint, and fleet training support (e.g., Total Ship Training System for ships).
- Describe in measurable and testable terms, when relevant, the missions, functions, or attributes used to optimize manpower, personnel readiness requirements.
- Identify MPT Total Ownership Cost (TOC) savings achieved through analysis of design (human factors, workload, KSAs, resources, and tools) for all tasks allocated to humans required for the efficient operation, employment, and support of the system.
- Describe any safety, occupational health, and environmental compliance requirements that reduce the risk of fatalities, injury, illness, or disability and death of the operators, maintainers, and support personnel.

- Describe habitability requirements for facilities (berthing, personal stowage, food service, medical, religious, security, recreational and lounge spaces), and ambient environment requirements (e.g., noise, lighting, heating, air conditioning, and ventilation, workspace layout, etc.) (Department of Defense, 2009e)

Finally, several System Engineering (SE) Reviews occur prior to exiting the E&MD phase. The SE Reviews include the Test Readiness Review (TRR), the Production Readiness Review (PRR), the System Verification Review (SVR), and the Functional Configuration Audit (FCA). In all, the reviews are in place to ensure the designed system meets the specified requirements and capabilities but also, to allow Low Rate Initial Production and Full Rate Production to occur. As members of an Integrated Product Team, HSI practitioners are fundamental to the success of these reviews. HSI input will ensure the designs are functional from the users' perspective with minimal risk to them.

The Technical Outputs are similar to those in the Technology Development phase; however, an Initial Product Baseline (IPB) is required for all class one-configuration changes. As stated previously, IPTs are required to incorporate into the IPB the following:

> Functional and physical characteristics of the Configuration Item, any joint and combined operations that the configuration item, functional and physical characteristics used for production acceptance testing, and tests that are required for the deployment, installation, support, training, and disposal of the Configuration Item. (Defense Acquisition University (DAU), 2010)

Section (c) provided an overview of HSI activities in the Engineering and Manufacturing Development phase. See Table 4 for a summary of HSI activities during the E&MD phase. Section (d) will provide an overview of the same issues for the Production and Deployment phase.

Table 4. E&MD Phase HSI Activity Summary

HSI Activity	Publication	IDAT&L Activity
1. Monitor activities to reduce risk.	DoDI 5000.02, DAG (2010) and Shattuck (2009)	Production and Manufacturing activities
2. Review processes for HSI emphasis for MDA updates.	DoDI 5000.02, DAG (2010) and Shattuck (2009)	Acquisition Strategy and APB
3. Provide HSI board members for RFP reviews.	DoDI 5000.02, DAG (2010) and Shattuck (2009)	Source Selection Evaluation Board (SSEB)
4. Perform Modeling and Simulation activities: human performance modeling; mitigation of risk and safety issues.	DoDI 5000.02, DAG (2010) and Shattuck (2009)	Prototype Development
5. Provide Manpower, Training, Personnel, HFE and Habitability updates due to mission capability, organization or funding change.	DoDI 5000.02, DAG (2010) and Shattuck (2009); service policies	Product Support Plan (PSP) and the Performance-Based Logistics (PBL) Strategy
6. Identify Training requirement; Optimize Manpower/Personnel readiness requirements; Identify MPT Total Ownership Cost (TOC); Describe ESOH requirements; Describe Habitability Requirements.	OPNAVINST 5310.23, Air Force 711th HSI Development Guide; Army MANPRINT documents	Capability Production Document (CPD)
7. Provide HSI input to ensure the designs are functional from the user's perspective with minimal risk to them.	OPNAVINST 5310.23, Air Force 711th HSI Development Guide; Army MANPRINT documents	System Engineering Reviews: Test Readiness Review (TRR), the Production Readiness Review (PRR), the System Verification Review (SVR), and the Functional Configuration Audit (FCA).
8. Participate in an IPT to provide functional and physical characteristics for the configuration Items.	OPNAVINST 5310.23, Air Force 711th HSI Development Guide; Army MANPRINT documents	Technical Outputs: IPB; Same as TD phase

d. Production and Deployment Phase

> The overall focus of the Production and Deployment phase is to 'complete the development of a system or increment of capability, leveraging design considerations; complete full system integration; develop an affordable and executable manufacturing processes, complete system fabrication, test and evaluation'. (DAU Online, 2010)

The purpose of the Production and Deployment (P&D) phase is to achieve an operational capability that satisfies the mission need. This phase consists of two efforts: Low Rate Initial Production (LRIP) and Full Rate

Production and Deployment (FRP&D). The phase begins after a successful Milestone C review. The Full Rate Production Decision Review (FRPDR) separates the two efforts. HSI practitioners assist in these efforts by participating in integrated product teams and providing updates to documentation.

Three reviews take place at the beginning of the Production and Deployment phase. These reviews include the Operational Test Readiness Review (OTRR), the Assessment of Operational Test Readiness (AOTR), and the Physical Configuration Audit (PCA). The OTRR is required prior to Initial Operational Test and Evaluation (IOT&E), which assesses the operational capabilities, suitability and effectiveness of the product. The AOTR occurs upon demonstration of those operational capabilities. The PCA determines if:

> Design documentation matches the item as specified in the contract; determines that the manufacturing processes, quality control system, the measurement and test equipment as well as training programs are planned, tracked, and controlled; and defines the starting point for controlling the detail design and establishing a product baseline. (Shattuck, 2009)

HSI participation in these reviews is essential. Each review employs a checklist that is used to evaluate the systems. The checklists include activities such as Program Management, Logistics, Testing, Interoperability, etc. The OTRR checklist, for example, contains 96 HSI evaluation activities (out of a total of 143 items). The PCA contains 143 HSI items.

HSI is also present in the Defense Acquisition Program Support (DAPS) Methodology for System and Software Engineering. The methodology provides examples of HSI domain activities and provides criteria to evaluate the activities. Although the reference is not used extensively in this thesis to identify the HSI activities for the cost estimation process, it should be considered for future research. A DAPS example of the manpower domain guidance is as follows:

> Manpower factors include job tasks, operation and maintenance (O&M) rates, workload, and operational conditions used to determine the number and mix of military and DoD civilian manpower needed to operate, support, maintain and provide training for the system.
>
> DoDD 5000.1 requires the Component Services to plan programs within projected future year manpower availability. Program manpower requirements should be based on studies and analyses that consider all operational facets of the Concept of Operations (CONOPS) to account for the manpower mix, and the impact on any established Service-level constraints on manpower end strength. (Department of Defense, 2000a)

Other HSI activities in the P&D phase include updating the Product Support Plans (PSP) and verifying Warfighter requirements in the Pre-Initial Operational Capability (IOC) review. As stated previously, HSI practitioners are not directly involved in writing the PSP but work with logisticians to update HSI criteria (requirements and performance metrics use to optimize the system) within the document. The IOC review updates configuration control changes, notes deficiency correction statuses within the system, and defines the maturity of the system.

Two of the most important aspects of the P&D phase are the Initial Operational Test and Evaluation (IOT&E) and the Live Fire Test and Evaluation (LFT&E) activities. HSI practitioners (as part of IPTs) help to identify testable HSI metrics for these tests. OT&E activities occur prior to Low-Rate Production decisions. The OT&E ensures that suitability and effectiveness meets the requirements of the “Warfighter, government civilians, and DoD contractors that will operate, maintain, and support the system, and those who will train them” (Shattuck, 2009). The LFT&E tests for the vulnerability or lethality of the system. HSI is indirectly involved in this testing; however, practitioners can learn how the system design affects the susceptibility and recoverability of the system, thus mitigating safety and mishap concerns.

Finally, scheduling or funding cuts may remove HSI requirements. Therefore, prior to the FRP, the Acquisition Strategy, Acquisition Plan, Source Selection Plan, RFPs and Final Product Baseline documents receive HSI criteria updates. This is the last line of defense in advocating for the representative users of the product. These documents, as well as manpower estimations, economic analyses, Critical Safety List items, PESHE and TEMP, will be reviewed at the FRP by the MDA.

Section (d) provided an overview of HSI activities in the Production and Deployment phase. See Table 5 for a summary of HSI activities during the P&D phase. Section (e) will provide an overview of the same issues for the Operation and Support phase.

Table 5. P&D Phase HSI Activity Summary

HSI Activity	**Publication**	**IDAT&L Activity**
1. Provide updates to system documentation; Review system for HSI input. Program Management, Logistics, Testing, Interoperability system evaluation processes using DAPS methods.	Shattuck, 2009; DoDD 5000.1	Operational Test Readiness Review (OTRR), the Assessment of Operational Test Readiness (AOTR), and the Physical Configuration Audit (PCA)
2. Verify Warfighter requirements; 3. Update PSP HSI criteria (requirements and performance metrics use to optimize the system) within the document.	Shattuck, 2009	Product Support Plans (PSP) and Pre-Initial Operational Capability (IOC) review
4. HSI (as part of IPTs) help to identify testable HSI metrics. 5. OT&E: Ensure that suitability and effectiveness meets the requirements 6. LFT&E: Lessons learned from system design affects the susceptibility and recoverability of the system.	Shattuck, 2009	Initial Operational Test and Evaluation (IOT&E) and the Live Fire Test and Evaluation (LFT&E)
7. HSI criteria updates.	Shattuck, 2009	Acquisition Strategy, Acquisition Plan, Source Selection Plan, RFPs and Final Product Baseline; manpower estimations, economic analyses, Critical Safety List items, PESHE and TEMP

e. Operation and Support Phase

> Life-cycle sustainment planning and execution seamlessly span a system's entire life cycle, from Materiel Solution Analysis to disposal. It translates force provider capability and performance requirements into tailored product support to achieve specified and evolving life-cycle product support availability, reliability, and affordability parameters. (DAU Online, 2010)

The purpose of the Operations and Support (O&S) phase is to "execute a support program that meets materiel readiness and operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle" (DAU Online, 2010). The O&S phase fulfills this purpose with two efforts: Life Cycle Sustainment and Disposal. HSI practitioners assist in supportability assessments, conduct modeling and simulation (M&S) testing, and provide updates to documentation. The subsequent paragraphs describe HSI assistance during sustainment and disposal.

During sustainment, the program manager and logisticians are concerned with the operational readiness and safety of the system. To maintain the readiness and safety of the system, supportability assessments and M&S activities take place to determine possible system improvements. HSI practitioners can assist in these processes by contributing to the supportability analysis, and supporting modeling and simulation studies. During these M&S studies, sustainability and mission effectiveness can be assessed. Lessons learned during operational field-testing are used for modifying subsequent system increments. Because of these changes, each increment requires an update to the CDD, CPD, and Key Performance Parameter (KPP) documents.

Follow-On Test and Evaluation is performed when a system (or product) is tested in an operational environment. During this phase of testing, verification of the following suitability effectiveness aspects occurs:

> Availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, manpower supportability, logistics supportability, and training requirements, environmental conditions of use scenarios (i.e., weather and climatic conditions, terrain effects, battlefield disturbances, and enemy threat conditions), mission length performance, vulnerability to countermeasures, and susceptibility of a system. (Shattuck, 2009)

Disposal is the final process of any defense acquisition program. Disposal costs are a small portion of the system's total life cycle cost; however, cost decisions occur prior to Milestone B (See Figure 8). The Defense Acquisition Guidebook (2010) states that program managers must determine the cost associated with "identification of plans for minimization and/or a safe disposal of hazardous materials, wastes, and pollutants associated with the system, and a compliance schedule for National Environmental Policy Act (NEPA)" (DAU, 2010, p. 283). Although indirectly associated, HSI practitioners (i.e., Environmental, Safety and Occupational Health) provide input to help determine these costs. HSI practitioners ensure that environmental precautions (i.e., hazardous material exposure, safety measures and risk mitigation) that will affect the user are included in programs.

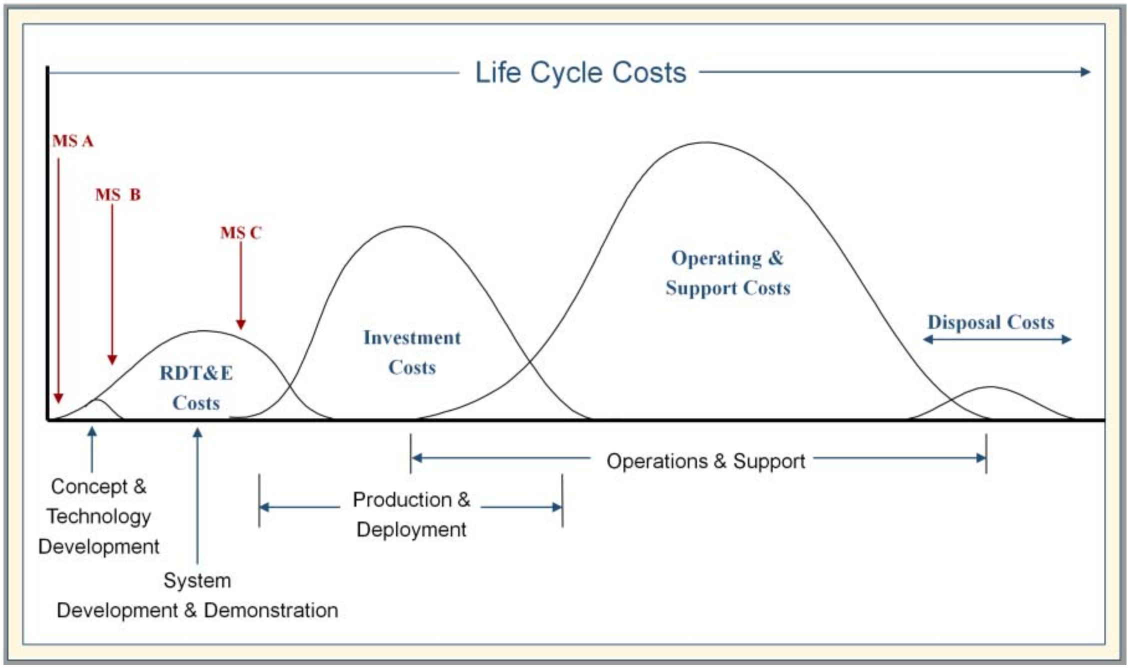

Figure 8. Weapon System Timeline and Life Cycle Cost Categories (From Mislick, 2009)

Finally, the technical review process that occurs during the O&S phase is the In-Service Review (ISR). The ISR "ensures that the system is operationally employed; system risk is well-understood, properly managed, and designed to describe and characterize the health of the system and provides assessments that are measureable for risk, readiness, technical status and, trends" (Shattuck, 2009). Although the Systems Safety Working Group and the Integrated Logistics Management Team conduct the ISR, it must receive contributions from HSI practitioners to ensure the system is performing as specified. Table 6 summarizes the HSI activities during the O&S phase.

Table 6. O&S Phase HSI Activity Summary

HSI Activity	Publication	IDAT&L Activity
1. Maintain the readiness and safety of the system, supportability assessments and M&S activities take place to determine possible system improvements; 2. Assess sustainability and mission effectiveness.	DAG, 2010, Shattuck, 2009	Sustainment supportability
3. Assist in providing updates due to system increment improvements.	DAG, 2010,	CDD, CPD, and Key Performance Parameter (KPP) documents
4. Assist in verification of the following suitability effectiveness	DAG, 2010,	Follow-On Test and Evaluation
5. HSI practitioners (i.e., Environmental, Safety and Occupational Health) provide input for environmental precautions.	DAG, 2010,	Disposal
6. HSI practitioners provide input to ensure the system is performing as specified.	Shattuck, 2009	In-Service Review (ISR).

Sections (a) through (e) have identified HSI activities from Concept identification to Disposal. It is now possible to create a more accurate picture of where HSI activity costs can occur as well as possible drivers that can contribute to the cost estimation processes. The next section will provide an overview of the cost estimation techniques, methods and processes used to develop a new HSI cost estimation process.

B. COST ESTIMATION TECHNIQUES, METHODS AND PROCESSES

> Cost estimating, as part of a total systems analysis, provides an analytic underpinning to support decision makers. (Nussbaum, 2010)

This section discusses the basic steps of cost estimation. The topics include Cost estimation purpose, scope, ground rules and assumptions; Modeling and identification of cost drivers, and cost estimation methodology.

1. Purpose, Scope, Ground Rules and Assumptions

In any cost estimation activity, there are several issues that need to be determined at the beginning of the process. These issues include the purpose, scope, ground rules, and assumptions for the cost estimation process about to be undertaken. In keeping with this approach, this section makes explicit each of these issues.

a. Purpose

The purpose of the present effort is to refine current cost estimation processes that include HSI activities that take place during the entire acquisition life cycle. The refined processes will be used during the AoA as well as during other activities such as the program office estimate and the baseline cost estimates.

b. Scope

The cost estimation process will attempt to address all HSI activities throughout the entire acquisition life cycle. The process is intended to be generic in nature so that it can be applied to any military service and to any type of system. However, the research effort will emphasize issues such as development/operation test and evaluation processes, program increments, operation and support, and environmental costs. The cost estimation process should also include risk and cost relationships.

c. Ground Rules

The present effort is constrained by manpower (this thesis is an individual effort by one graduate student), by time (this thesis had to be completed within nine months) and by availability of other resources such as cost data and guidance, subject-matter experts, and funding for travel.

d. *Assumptions*

The work reported herein is only an initial effort; additional work will be required to refine the cost estimation process for HSI activities. The process is based upon the data that were collected from subject-matter experts who were available. Although the current research is based predominantly on peacetime operations, future efforts should concern war-related cost.

2. Identification and Modeling of Cost Drivers

The life-cycle phase review described earlier identified HSI activities that are essential to the AoA cost estimate process. In performing cost estimates, HSI driver trade-offs must also be determined. These estimates include the activities that help determine the projected cost of all HSI domains. However, emphasis is placed on manpower, training, personnel, and human factors engineering. This section discusses these cost drivers, cost estimate relationships, and modeling efforts.

a. *Manpower Cost Drivers*

Manpower cost drivers and relationships are the most commonly used and accepted variables in cost estimate methodology. The publications that discuss Manpower cost drivers and relationships include the Directive-Type Memorandum (DTM) 09-007 and the 2010 Federal Acquisition Regulations.

The DTM-09-007 states that manpower costs are identified as "specific unit, organization, function, mission, or defense acquisition program… analysts should report the full costs of both military and civilian DoD manpower" (DoD, 2010a, p. 5). Cost drivers such as man-hour costs, are incorporated into the O&S phase of the life cycle. Although it is imperative to include the proper workforce mixture (military, civilian and contractor workloads), the highest performance at minimum cost is needed. Therefore, AoA processes include estimates for comparison between these entities. These costs do not usually occur once, but span over the life of the system. For example, at any given point in time, the cost of a military member will include:

- Base pay,
- Basic substance and housing allowance,
- Cost of medical care, and
- Retirement

The contractor cost may be short-lived. Contractor costs usually include development or short-term services involving testing, logistics, transportation, and will not include added benefits. Defining manpower business rules and methodology is the next step for defining manpower cost estimation relationships.

The DTM-09-007 defines business rules and methodology for the workforce mix (DoD, 2010a). In order to determine appropriate manpower costs, composite rates for Manpower must be used. The Office of Undersecretary of Defense website provides these rates. Appendix A of this thesis also contains the current fiscal year composite rates. Furthermore, determining manpower cost includes describing direct and indirect costs.

Direct costs that are often overlooked include the deferred compensation costs (liabilities/retirement or pay-as-you-go cost) that DoD civilians may incur (p. 7). Many tests and evaluations during development invoke hearing conservation programs. Occupational Health costs incorporate these programs and include hearing test costs or disability costs after the fact. The DTM-09-007 states the “full costs of manpower include current and deferred compensation costs paid in cash and in-kind, as well as non-compensation costs” (DoD, 2010a, p. 7). Short-term costs increase when workforce duration lengthens. These costs are associated with activities such as establishing or modifying day care and commissary services for military locations. Table 7 includes an overview of the direct costs incurred.

Table 7. Direct Labor Cost Elements for Military and DoD Civilian Personnel (From DTM-09-007; DoD, [2010])

	Military		Civilian	
	DoD	Other Federal Agency	DoD	Other Federal Agency
Variable Costs in Short Run	Basic pay Allowances and special pays Incentive pays Health benefit, active duty and dependents Social Security and Medicare Retired pay (accrual) Travel/PCS/transportation subsidy Education assistance Health benefit, retiree (>65 MERHCF accrual) Training costs (amortized over years of practice) Recruitment, advertising, etc. (amortized)	Concurrent receipt (Treasury) Military Retirement (Treasury) MERHCF (Treasury) Child education (Education)	Basic pay/locality pay Allowances and special pays Incentive/Performance awards Health benefit (government share of FEHBP) Social Security and Medicare Retired pay (government share) Travel/PCS/transportation subsidy/relocation bonus Education assistance Overtime/holiday/other pays Life insurance/worker's compensation benefits Recruiting, advertising, etc. (amortized)	
Fixed Costs in Short Run	Child development Family support services Discount groceries		Child development	
Deferred Pay-As-You-Go Costs	Health benefit, retiree (<65 retiree and family) Health benefit, other (TAMP and CHCBP) Discount groceries, retiree Separation pay and travel Unemployment benefits Death gratuities Survivor benefits	VA benefits (Veterans Affairs) Employment training (Labor)	Severence health benefit Severence pay/incentive	Retirement benefit (CSRS unfunded) Health benefit Life insurance benefit

The 2010 Federal Acquisition Regulation section 31.203 defines indirect costs. Indirect costs are those costs that are “not directly identified with a single final cost objective, but identified with two or more final cost objectives or with at least one intermediate cost objective” (Department of Defense [DoD], U.S. General Services Administration [GSA], National Aeronautics and Space Administration [NASA], 2010). Direct costs can be treated as indirect costs if the dollar amount is minor and the accounting treatment is applied consistently. These cost must however, produce results that are the same as if treated as a direct cost (DoD et al., 2010). These costs include machinery, facilities, materials and supplies; however, they vary from contract to contract.

Frequently, DoD organizations write contracts for HSI services; therefore, evaluating indirect cost is essential. Unlike the work completed by DoD or civilians, many of the liabilities for contracting are not under sovereign immunity and must be factored in to the cost equation. If contract negotiations leave out goods, benefits, and services for government-furnished property and cost of upper-level management, contracts will most likely increase in cost over time.

The DTM-09-007 states that these overlooked contract costs can include:

- Liability to third parties;
- Reimbursements to a contractor for payments the contractor, its insurance company, or the Department of Labor make pursuant to Public Laws 85-608 and 77-784 (References (i) and (j));
- Reimbursements the Department of Defense is obligated to make with respect to publicly sponsored insurance (e.g., air carrier insurance sponsored by the Federal Aviation Administration pursuant to title 49, U.S.C. (Reference (k)) and;…,
- The value of the authorization and consent to infringe privately held patents with freedom from monetary damages and injunctive relief that would otherwise prevent a contractor from performing the function. (DoD, 2010, p. 12)

As with any system, analyzing the operational tempo and mission requirements will provide other influential cost drivers. Johnson, Osborn, Previc, and Prevost (2005) paper provides an excellent example of influential cost drivers.

The authors addressed drivers by performing a top down requirements analysis (TDRA). This approach determined that the highest manning occurred during operational tempos under battle readiness and wartime amphibious assault operations. These conditions lead to increased watch standing and manning requirements. By including these types of influential drivers in the estimate, the impact of such outcomes as the need for equipment redesign, lower than expected performance, and delays in schedule can be determined. These types of drivers are essential in producing reliable estimates for HSI related work.

b. Personnel and Training Cost Drivers

Personnel and Training domains also provide important cost drivers and relationships. Each grade, rank, rate, general service position or manpower contract type will have specific associated costs and are; therefore, factored into the estimate for O&S phase. Determining the personnel requirements and recruiting efforts for supplying the needed operators and maintainers of the system is another personnel cost.

The training costs involved include developing and updating training strategy and plans, as well as developing effective training methods and tools. To produce qualified maintainers and operators for the various training pipelines, these methods and tools are essential. Training drivers include the technologies used as well as the test and evaluation of technology. Drivers should also consider the manpower cost to deliver the instruction. Therefore, both the R&D and O&S life-cycle phases consider training costs.

c. Human Factors Engineering (HFE) Cost Drivers

The HFE domain dominates Research and Development (R&D) cost estimates. The HFE cost drivers in R&D are essentially the cost of development, testing and evaluation. Developing tools, analyzing tasks and evaluating human-technology interactions are typical activities for HFE practitioners. These activities can account for hundreds and even thousands of man-hours contribute to these methods and research processes and thus should qualify as a high driver.

Modeling and Simulation (M&S) costs occur in practically every HSI domain activity (i.e., manpower, training, safety and survivability) in a acquisition program. For example, HFE costs drivers that relate to manpower include function allocation, workforce role determination, workload reduction, as well as the inherent workload risk and affordability determinations. Therefore, M&S is a high driver depending on the cost of technology, length of service, and the needs determination for modification of design. Use of analogous systems and comparable tools help determine the cost estimations.

d. Environment and Safety Cost Drivers

As stated previously, Environment and Safety have their own process owners. Periodically, practitioners must review and update safety and environmental inspection procedures, design requirements, and regulations. Besides licensure and environmental fees, a majority of safety costs are comprised of man hours required to perform needed administration and procedural requirements. The Environmental, Safety and Health Cost Analysis guide (1998) define two drivers of environmental cost:

- Public Law 103-337, Section 815, Environmental Consequence Analysis of Major Defense Acquisition Programs, and
- Department of Defense Regulation 5000.2-R, Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated information System (MAIS) Acquisition Programs, Section 4.3.7. (p. 9)

These programs discuss “materials to be used, the mode of operations and maintenance, requirements for demilitarization, and methods of disposal, after consideration of all pollution prevention opportunities and in light of all environmental mitigation measures to which the Department expressly commits” (Air Force Materiels Command, 1998).

The Environment and Safety practitioners work hand in hand with HFE practitioners when designing the system for safe and effective handling, operation, and disposal. These are mainly manpower intensive drivers; however when a system has a lifespan that exceeds initial life expectancy, the cost of reinstallation, deployment, upgrades and disposal will skyrocket. An example of a system that has gone beyond the normal lifespan and has required significant modification is the Iowa class battleships. Commissioned in 1942, the Iowa class ships received numerous modifications. Defense and survivability modifications included electronic warfare suites, close-in weapon systems, BGM-109 Tomahawk Land Attack Missiles, and RGM-84 Harpoon anti-ship missiles. After 48 years of service, the ships were finally decommissioned.

e. Occupational Health, Habitability and Survivability Cost Drivers

The final HSI domains of Occupational Health, Habitability and Survivability are man-hour intensive. These domains contribute cost drivers indirectly to the cost estimation. They provide cost variables for the R&D phase of the life cycle. Bratt, Doganiero, and Spencer (1998) discuses these human error and mishap related variables.

As stated previously, indirect manpower costs include deferred compensation (e.g. disability). Bratt, et al. (1998) suggests that it is important to substantiate the driver causal factors; otherwise, consequences may be undetermined for any system development. Mishap data is relevant to any platform whether it is aircraft, ship or land based (including peace and war operations). The leading causes of mishaps are human error and equipment failure.

Human error may occur from someone having a bad day, a crisis in their personal life, delayed or incorrect decision-making, or even unfamiliar or faulty written procedures. In many cases, the equipment failure also stems from human error (e.g. errors in design considerations etc.). Manpower reduction, poor or inadequate human factors engineering, and lack of attention to safety considerations are among the factors that contribute to these efforts. The potentially enormous price incurred for these errors translates into cost such as:

- disposal costs,
- medical care,
- disability and rehabilitation,
- redesign and modification, and
- training

Identifying and mitigating the health risks involved in system development is a cost avoidance measure. Although not normally considered in a cost estimate, these potential outcomes certainly should be included. Human error is unavoidable, though it can be reduced. Cost estimates must include mitigation of these risks and mishaps (apparent in any system) and be compensated for when they occur.

f. Cost Modeling

HSI cost modeling can be adapted from current models in Occupational Health and System Engineering. These modeling activities are dependent on the system and target audience description for the intended use of the system. This section discusses these various models used in cost estimation of Occupational Health and Systems Engineering.

Bratt et al. (1998) reports on a 1997 Army weapon hazard study that linked possible health hazards to clinic services. Specifically, the authors summarized their work as follows:

> Incidence rates and calculated costs based on industry-wide data on injuries, lost time, hospitalization, and disability, and this framework provides a method to reasonably estimate the medical and lost military manpower costs of unabated health hazards associated with Army materiel. (p. 443)

The article addressed the effectiveness of the health risk assessment and management system while also contributing to the control of life cycle cost. The article provides the severity levels and hazard probabilities needed for cost estimations (see Figure 9, Tables 8 and 9). The resource also includes valuable equations for factoring hazard variables into the cost estimations. A full variable list and explanations are available in Appendix B.

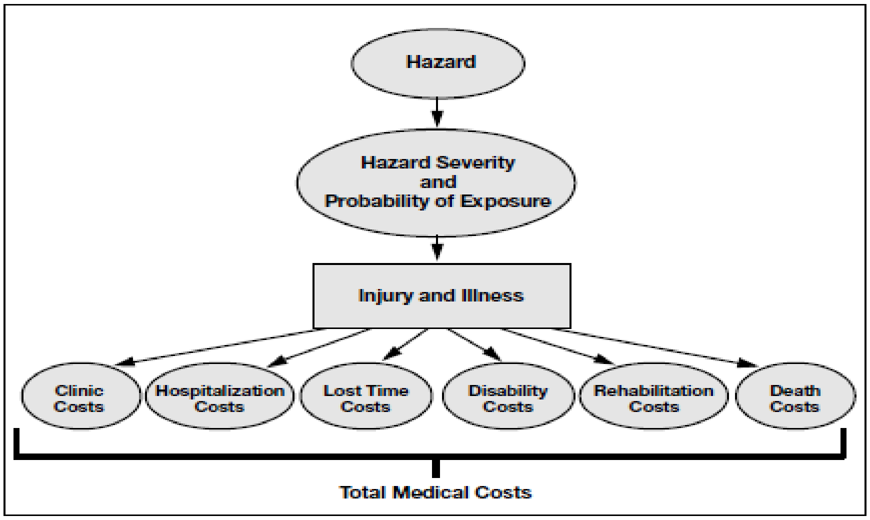

Figure 9. Cost Components from a Single Hazard (From "Estimating the health hazard cost," 1998)

Table 8. Risk Assessment Codes (RAC) and Costs (Thousands of Dollars) Matrix (from "Estimating the health hazard cost," 1998)

		Hazard Probability (P_e)				
		Frequent	Probable	Occasional	Remote	Improbable
Hazard Severity (S_k)		A (.9)	B (.5)	C (.2)	D (.01)	E (.001)
I (1)	Catastrophic	1 ($15,088)	1 ($8,471)	1 ($3,508)	2 ($365)	3 ($216)
II (.1)	Critical	1 ($1,410)	1 ($783)	2 ($313)	3 ($16)	4 ($1)
III (.01)	Marginal	2 ($137)	3 ($76)	3 ($30)	4 ($2)	5 ($0.152)
IV (.001)	Negligible	3 ($13)	5 ($7)	5 ($3)	5 ($0.148)	5 ($0.015)

Notes: The calculations are based on a high risk system. The numbers 1, 2, 3, 4, and 5, in the columns under Hazard Probability are the RACs. The numbers in parentheses in the columns under Hazard Probability are the medical costs that are incurred for a given RAC if no intervention occurs.

Table 9. Cost Component Equations (From “Estimating the health hazard cost,” 1998)

Related Cost Component	Component calculation	Equation
All (except death costs)	Number of people exposed to hazard	$N_e = P_e \times N_s \times N_{ps}$
Clinic costs	Number of people injured or ill	$N_i = N_e \times S_k \times I_i$
Clinic costs	Clinic costs	$C_c = N_v \times F_c$
Clinic costs	Number of clinic visits	$N_v = N_e \times S_k \times [V_e + (I_i \times N_c)]$
Hospitalization costs	Hospitalization costs	$C_h = N_h \times F_h$
Hospitalization costs	Number of persons hospitalized	$N_{ph} = N_e \times S_k \times I_h$
Hospitalization costs	Number of hospital days	$N_h = N_e \times S_k \times I_h \times \Sigma (D_{hd} \times D_{ho})$
Lost time costs	Lost time costs	$C_l = N_l \times W_d \times B_r$
Lost time costs	Number of persons losing time	$N_{pl} = N_e \times S_k \times I_l$
Lost time costs	Number of lost workdays	$N_l = N_e \times S_k \times I_h \times \Sigma (D_{ld} \times D_{lt})$
Disability costs	Disability costs	$C_{dl} = N_e \times S_k \times I_v \times T_v \times \Sigma (D_v \times B_v) \times 12$ mo/yr $+ [(I_t \times B_t) + (I_p \times B_p)]$
Disability costs	Number of persons disabled	$N_{pd} = N_e \times S_k \times (T_v \times I_v + I_t + I_p)$
Rehabilitation costs	Rehabilitation costs	$C_r = N_e \times S_k \times I_v \times T_v \times \Sigma D_r \times Q_r \times B_r)$
Rehabilitation costs	Number of rehabilitation cases	$N_r = N_e \times S_k \times I_v \times T_v \times \Sigma D_r \times Q_r$
Death costs	Death costs	$C_{de} = (N_{de} \times B_{de})$
Note: Number of people exposed to hazard ($N_e = P_e \times Ns \times N_{ps}$) is a common term related to all cost components except death costs.		

Since the System Engineering community undoubtedly influences the HSI community, Valerdi (2005) provides further development of possible cost estimation relationships that are fundamental to HSI-derived models.

Valerdi identifies system engineering effort (in person-months) using the Constructive Systems Engineering Cost Model (COSYSMO). This model includes four primary drivers (see Table 9), as well as fourteen effort multipliers/cost drivers (See Table 10).

Table 10. Size Drivers and Corresponding Data Items (From “The Constructive Systems Engineering Cost Model,” 2005)

Driver Name	Data Item
# of System Requirements	Counted from the system specification
# of Major Interfaces	Counted from interface control document(s)
# of Critical Algorithms	Counted from system spec or mode description docs
# of Operational Scenarios	Counted from test cases or use cases

Table 11. Cost Drivers and Corresponding Data Items (from “The Constructive Systems Engineering Cost Model,” 2005)

Driver Name	Data Item
Requirements understanding	Subjective assessment of the system requirements
Architecture understanding	Subjective assessment of the system architecture
Level of service requirements	Subjective difficulty of satisfying the key performance parameters
Migration complexity	Influence of legacy system (if applicable)
Technology risk	Maturity, readiness, and obsolescence of technology
Documentation to match life cycle needs	Breadth and depth of required documentation
# and Diversity of installations/platforms	Sites, installations, operating environment, and diverse platforms
# of Recursive levels in the design	Number of applicable levels of the Work Breakdown Structure
Stakeholder team cohesion	Subjective assessment of all stakeholders
Personnel/team capability	Subjective assessment of the team’s intellectual capability
Personnel experience/continuity	Subjective assessment of staff consistency
Process capability	CMMI level or equivalent rating
Multisite coordination	Location of stakeholders and coordination barriers
Tool support	Subjective assessment of SE tools

Valerdi initially expresses System Engineering effort in terms of historical data, size drivers and effort multipliers. The final derived formula for system engineering effort, however, includes weighted variables for the effort multipliers (See Figures 10 and 11). These equations identify the relationships between the effort multipliers and the cost factor variables. Each factor is subject to the changes in system use such as “redesign, reimplementation, and retest” (Valerdi, 2005, p. 41). Factors are also impacted by complexity and volatility. The model encompasses periodic adjustment for the drivers. Furthermore, Valerdi states that increases or decreases to variables are system or criteria dependant.

Equation 2 $$PM_{NS} = A \cdot (Size)^{E} \cdot \prod_{i=1}^{n} EM_{i}$$

Where:

PM$_{NS}$ = effort in Person Months (Nominal Schedule)

A = calibration constant derived from historical project data

Size = determined by computing the weighted sum of the four size drivers

E = represents economy/diseconomy of scale; default is 1.0

n = number of cost drivers (14)

EM$_i$ = effort multiplier for the i_{th} cost driver. Nominal is 1.0. Adjacent multipliers have constant ratios (geometric progression). Within their respective rating scale, the calibrated sensitivity range of a multiplier is the ratio of highest to lowest value.

Figure 10. COSYSMO Operational Form (From "The Constructive Systems Engineering Cost Model," 2005)

Equation 6 $$PM_{NS} = A \cdot \left(\sum_{k} w_e \Phi_e + w_n \Phi_n + w_d \Phi_d \right)^{E} \cdot \prod_{j=1}^{14} EM_j$$

Figure 11. Final COSYSMO CER (From "The Constructive Systems Engineering Cost Model," 2005)

In Figure 11, the symbol expressions include:

k = number of requirements, interfaces, algorithms, and operational scenarios (REQ, INTF, ALG, OPSC)

w = weight

e = easy

n = nominal

d = difficult

Φ = driver count

Next, Valerdi establishes categories for the COSYSMO model factors (See Figure 12). In HSI, identity of such factors is necessary due to the role of the HSI practitioner in policy writing, development, testing, modeling and simulation of systems.

UNDERSTANDING FACTORS
- Requirements understanding
- Architecture understanding
- Stakeholder team cohesion
- Personnel experience/continuity

COMPLEXITY FACTORS
- Level of service requirements
- Technology Risk
- # of Recursive Levels in the Design
- Documentation Match to Life Cycle Needs

OPERATIONS FACTORS
- # and Diversity of Installations/Platforms
- Migration complexity

PEOPLE FACTORS
- Personnel/team capability
- Process capability

ENVIRONMENT FACTORS
- Multisite coordination
- Tool support

Figure 12. Cost Factor Clustering (From "The Constructive Systems Engineering Cost Model," 2005)

Finally, Figure 13 and Table 12 depict Valerdi's final cost model (and the acronym listing). The COSYSMO model provides the foundation that HSI models can build upon. Future HSI modifications should enhance this current model.

Equation 14

$$\log[SE\_HRS\_ADJ] = \log[SIZE] + \log[UNDERSTANDING] + \log[COMPLEXITY] + \log[OPERATIONS] + \log[PEOPLE] + \log[ENVIRONMENT]$$

Where

$$UNDERSTANDING = REQU * ARCH * TEAM * PEXP$$
$$COMPLEXITY = LSVC * TRSK * RECU * DOCU$$
$$OPERATIONS = INST * MIGR$$
$$PEOPLE = PCAP * PROC$$
$$ENVIRONMENT = SITE * TOOL$$

Figure 13. COSYSMO Model (From "The Constructive Systems Engineering Cost Model," 2005)

Table 12. COSYSMO Predictor Descriptions (From "The Constructive Systems Engineering Cost Model," 2005)

Predictor	Term	Description
S_1	log(REQ)	# of System Requirements
S_2	log(INTF)	# of Major Interfaces
S_3	log(ALG)	# of Critical Algorithms
S_4	log(OPSC)	# of Operational Scenarios
EM_1	log(RQMT)	Requirements Understanding
EM_2	log(ARCH)	Architecture Understanding
EM_3	log(LSVC)	Level of Service Requirements
EM_4	log(MIGR)	Migration Complexity
EM_5	log(TRSK)	Technology Risk
EM_6	log(DOCU)	Documentation to match lifecycle needs
EM_7	log(INST)	# and diversity of installations/platforms
EM_8	log(RECU)	# of recursive levels in the design
EM_9	log(TEAM)	Stakeholder Team Cohesion
EM_{10}	log(PCAP)	Personnel/Team Capability
EM_{11}	log(PEXP)	Personnel Experience/Continuity
EM_{12}	log(PROC)	Process Capability
EM_{13}	log(SITE)	Multisite Coordination
EM_{14}	log(TOOL)	Tool Support

3. Cost Estimation Methodology

Cost estimators typically use four methodologies. Each methodology is suited for different periods in the life cycle although they may be used in any of the life cycle periods. These methods are: engineering build-up (bottom-up technique); analogy; parametric; and expert opinion. This section discusses these methods and describe the manner in which they are used.

Acquisition programs frequently employ a Work Breakdown Structure (WBS) or a Cost Analysis Requirement Descriptions (CARD). When a detailed WBS (at the lowest level) is available for the system of interest, the engineering build-up method is the preferred cost estimation method. When other programs of a similar nature (complexity, technical or physical) are available, the analogy method is preferred. In general, whenever few actual costs are available early a program, similar programs are the most viable means for determining cost estimates.

The parametric method is preferred if the program is in the early stages of development and limited data (program and technical) are available. This method is similar to the analogy method. It uses similar system performance and design characteristics while determining cost element relationships (CER) on which to determine statistical inference. If these methods are not available, then it is possible to use expert opinion. It is also possible to use a combination of these methods, if the system allows. Reproducibility and sensitivity analysis are techniques used to improve the accuracy of the cost estimate. Figure 14 provides a comparison of these methods' advantages and disadvantages

Model Category	Description	Advantages	Limitations
Analogy	Compare project with past similar projects	Estimates are based on actual experience	Truly similar projects must exist
Expert Judgment	Consult with one or more experts	Little or no historical data is needed; good for new or unique projects	Experts tend to be biased; knowledge level is sometimes questionable
Bottoms-Up	Individuals assess each component and then component estimates are summed to calculate the total estimate	Accurate estimates are possible because of detailed basis of estimate (BOE); promotes individual responsibility	Methods are time-consuming; detailed data may not be available, especially early in a program; integration costs are sometimes disregarded
Parametric Models	Perform overall estimate using design parameters and mathematical algorithms	Models are usually fast and easy to use, and useful early in a program; they are also objective and repeatable	Models can be inaccurate if not properly calibrated and validated; it is possible that historical data used for calibration may not be relevant to new programs

Figure 14. Methodology Comparison (From Nussbaum, 2010)

Figure 15 provides recommendations for which method to use during various phases of the acquisition life cycle.

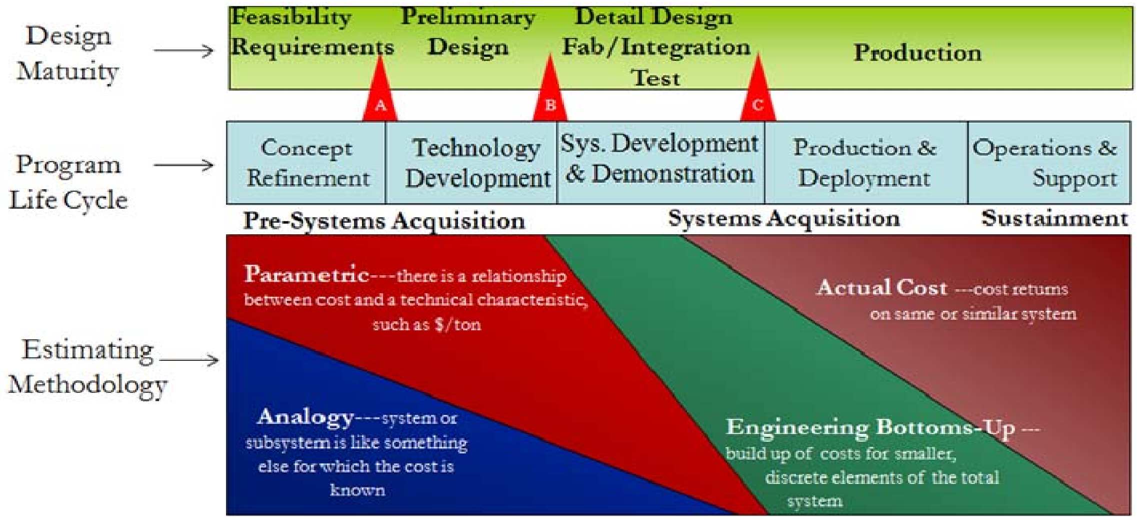

Figure 15. The Cost Estimating Process: Estimating Approaches and Cost Methodologies and Milestones (From Nussbaum, 2010)

A majority of HSI activities have not been defined in most system Work Breakdown Structures. Therefore, this thesis uses expert opinion to determine HSI costs during the acquisition life cycle. However, the long-term goal is to gain enough HSI cost data in similar systems to use the parametric method. This method will ensure a higher level of accuracy based on the CER used.

If a parametric method can be employed, CERs are determined based on the following formula:

Cost = f (technical, performance, schedule) (Nussbaum, 2010)

In doing so, it will be possible to use statistical techniques such as multivariate, bivariate, univariate analyses as well as log-linear analysis. The next step is to normalize the data in order to compare similar systems.

As stated in Nussbaum (2010), data normalization reduces content differences such as "elements of cost; technology similarities, and consistency in scope of work". However, the availability of historical HSI data limits data normalization for cost estimation. When comparing similar systems, it is also important to break down activities into common cost elements. For example, an estimate in one program may contain a combination SE/PM cost element but historical documents list these elements separately. Division of cost elements reduces replication. Mapping the differences in the same manner in estimation mitigates the likelihood of over- or under-estimating. This will be apparent in cost estimates involving HSI criteria since many process owners (HSI domain criteria) are cost oriented this way. Since HSI elements are typically under current processes (i.e., manpower, training, etc.), this will inevitably lessen the task of creating new factors to explain costs. The best estimation methods rely on the analyst's judgment and the data available.

The current thesis investigates methods for performing estimates involving HSI criteria. The thesis is intended as a resource to guide the HSI modification of current cost models and estimation methods.

C. HSI CONCEPT MODEL

The purpose of this section is to describe two HSI models that will inform the HSI cost estimation process. The models include domain variables, constraints, enablers, and cost drivers. The two HSI models are the 711th Human Performance Wing's HSI model, (23 July 2007) (see Figure 16) and the HSI Process Model developed by Miller and Shattuck (2007) (see Figure 17).

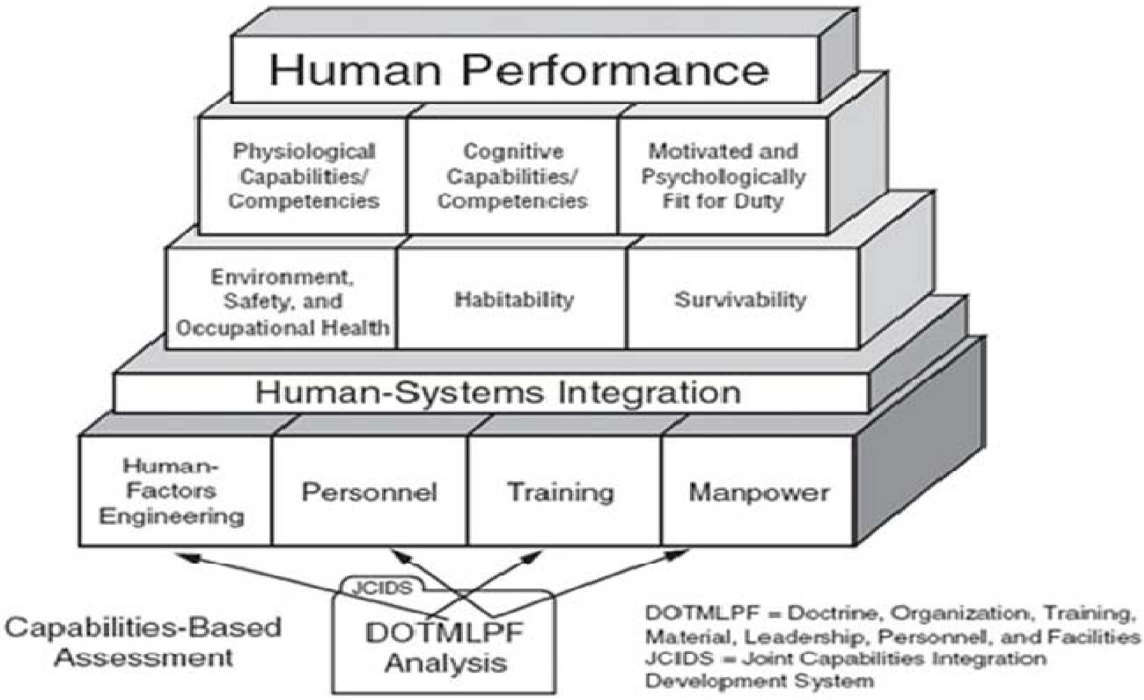

Figure 16. Linkages between the HSI process model and the Joint Capabilities Integration Development System gap analysis. (From "Human Systems Integration (HSI) in Education," 2007)

The Human Performance Wing HSI Model (see Figure 16) is described as follows:

> The four input domains [of HFE, Personnel, Training, and Manpower] greatly simplifies the challenges of forecasting the impact of HSI trade-offs through modeling and simulation, a necessary consideration given DOD initiatives for simulation-based acquisitions. In contrast, the ESOH, habitability, and survivability domains represent desired system attributes or behaviors not directly procurable; rather, they emerge through various combinations of the input domains. (Tvaryanas, Brown, & Miller, 2009)

Although the article provides an adequate assessment of the constraints and enablers of a system, it does not represent the cost variables associated with performance optimization. However, the model developed by Miller & Shattuck (2007), could prove useful for estimating the cost of HSI activities.

Weighting factors or cost inputs (relevant to previous systems seen in the initial block of domain advocacy), initiate processes depicted in the model. The factors/inputs that could augment those already listed in the Domain Advocacy block include Manpower Estimates, Training Technology Development costs, Modeling and Simulation (M&S), and Test and Evaluation (T&E) costs. The constraints and enabling factors of the model include schedule delays, contractor renegotiations, performance testing, and development failures. These factors interact with the inputs to optimize the system outcome.

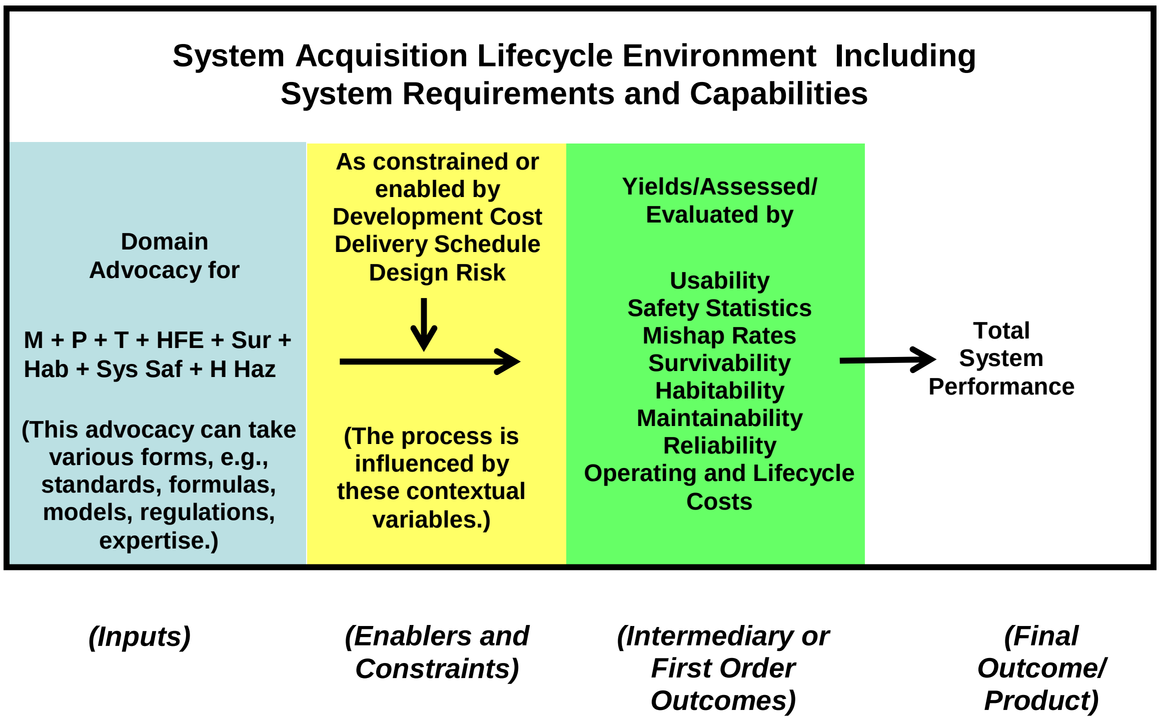

Figure 17. HSI Process Model (From Miller & Shattuck, 2007)

Miller and Shattuck (2007), state as “factors in the first two boxes combine, they produce effects that can be captured by outcome measures such as usability, survivability, habitability, maintainability, reliability, safety (indicated by safety statistics and mishap rates), operating and total life cycle costs” (p. 12). The outcome measures are further identified by cost high drivers such as deferred compensation, disability cost and cost avoidance and system engineering factors (i.e., mean time between failure, maintenance hours etc.). The product of all equations will be the total system performance of the human-system product. The Miller and Shattuck model is a more functional model (in terms of cost estimations) than the 711th model.

Most expert cost estimators agree, “simpler is better,” and that the use of sophisticated tools and methods of cost estimation comes with its own burdens. Many advanced methods utilize “black box” applications in which the user has little knowledge of the underlying algorithms or processes. Novice estimators must often use of these complicated cost estimation tools (e.g., ACEIT, SEER-H, SEER-S, PRICE-H, PRICE-S, etc.) until experience is gained. This thesis employs a relatively simple Microsoft ® Access based database to identify HSI activities and their associated cost. Excel-based operations perform the necessary activity calculations. This thesis will use the HSI process model by Miller and Shattuck (2007). However, the thesis will leverage the processes embedded in cost estimation tools such as the Automated Cost Estimating Integration Tool (ACEIT) and the Marine Corp Ground Training Cost estimation tool.

Section C reviewed HSI Concept models for future cost estimation processes. Section D will review current HSI cost estimation methods used by other countries and organizations.

D. CURRENT SERVICE HSI COST ESTIMATION METHODS

Reports by Canadian Defense Technology Center (DTC) (2006); Brooks, Greenley, Dyck, Salwaycott, Scipione and Shaw (2008); and Liu (2009) provide guidance for determining a method to perform HSI cost estimation. The Canadian Ministry of Defense initiated the DTC HFI program in 2003, which is equivalent to U.S. HSI.

> DTC is a formal collaborative arrangement between industry and academic experts in a particular technology, funded jointly by participants and the MOD. The participants work together to

generate and enhance the technology vital to the delivery of future UK Defence capabilities. (British Aerospace Systems, 2010)

The Canadian Defense Technology Center Report (2006) identifies five arguments including the cost considerations of five categories related to Human Factors Integration (HFI) in the overall cost estimate of a system (see Table 13). The purpose of this study was to make decisions on budget allocation regarding HFI activities. Due to a misunderstanding of the value of HFI and the inability to trace intangible benefits, previous work had not provided compelling evidence for including HFI into cost estimations. The arguments lay a foundation of cost factors and provide the rationale for incorporating HFI; however, the bases of these cost factors are sometimes vague or obscure.

Table 13. Human Factor Integration Arguments

Argument 1	HFI can reduce major costs.
Argument 2	HFI is increasingly required due to developments in technology.
Argument 3	HFI plays a critical role in identifying and mitigating operational risks.
Argument 4	HFI can draw on resources that enable an effective and efficient process.
Argument 5	Effective HFI requires early, complete and close involvement.

The report identifies the value of HFI contributions by providing successful (and non-successful) case studies related to HFI initiatives (or the absence of initiatives). The analyses performed on these case studies show the savings or expenditures related to specific HFI variables. The five Arguments and their related case studies are now described.

Argument 1 includes operational and developmental risk cost. Main costs include:

- Accident costs (system safety or human error),
- Lowered performance and mission failure, people and materiel resources,
- Inefficient development and implementation processes (Technology and Development phase; Integration phase of life cycle),
- Redesign cost (integrate phase), and
- Personnel costs (Procurement-training and recruitment)

Typical case studies within this category include aviation mishaps, equipment designs (rifles), unanticipated cost due to extra training, improper implementation and late design changes. In some cases, it is hard to determine the actual cost related to HFI. For example, the author incorporates full cost of machinery such as plane loss, but omits identification of hazards. This problem occurs when reporting cause of failure. It is important to perform accurate tradeoff analysis and identification of hazards for costs/health hazards relationships.

Argument 2 relates to complexity driven errors. Increased complexities in technology, mandated standards and/or regulatory actions support the argument for HFI. Tradeoff integration should provide insight into complexity related errors; however, the costs often do not consider these tradeoffs.

Argument 3 determines the need for identifying and mitigating operational risk. This occurs through raising awareness, identifying areas of uncertainty and providing a means for user input. User-guided input leads to a better design with less rework. A valid methodology (through modeling of potential problems) is the key to cost savings. Early identification of standards and substantiated requirements that can be used later in scenario development also saves cost.

Argument 4 indicates that HFI practitioners can utilize previous methodologies, principles and research to prevent repeating past mistakes. The report establishes a need for documenting these processes to mitigate future Human Factors problems.

Finally, Argument 5 states the need for cost estimation throughout the entire process of the life cycle. Four methodologies for cost estimation include Investigating (problems and constraints), Creating (solutions based on requirements), Evaluating (AoA), and Managing (resources, organization, etc.). Furthermore, the argument states the need for immersing HFI activities early in the process. This will allow practitioners to develop and maintain an efficient and cost effective solution.

The Defense Technology Centre report provides excellent examples of HFI problems and their associated costs. The report also provides provisional insight into requirements, validity and reliability, increased efficiency and the need for user involvement. However, future work should include detailed analysis of cost factors and their linkages to HFI domains across the life cycle.

Brooks et al. (2008) provides a second HSI cost process. The Canadian Department of National Defence (DND), in partnership with Defense Research and Development of Canada, provided a multi-year analysis of activities to demonstrate and validate an HSI approach for the Canadian Materiel Acquisition and Support community of DND.

From 2001 to 2004 an analysis of 31 HSI-related acquisition projects were completed and then reviewed for cost measures. The study produced measures in terms of immediate and extrapolated savings based on the HSI activities in these projects. The study also provided examples of future budget considerations such as incorporating cost estimation ranges. The purpose of the report was to establish the need for HSI. The report included the following topics: concept of HSI, development of HSI programs, team implementation, integration of HSI process, tools of HSI, case studies (evaluation, implementation, support, definition of tools and lessons learned) and cost tracking data for the application of HSI. The most relevant aspects of the report with respect to this thesis are the tool applications and the cost tracking data. The subsequent paragraphs summarize these aspects.

It is important to note that in the Canadian DND, HSI consists of five domains. In the U.S., the number of domains varies from one military service to another (U.S. Air Force, nine; U.S. Navy, eight; U.S. Army, seven domains). The Canadian DND combines the manpower and personnel domains and the system safety (SS) and health hazards (HHA) domains. The SS-HHA combination is equivalent to the U.S. domains of system safety, occupational health, survivability, and environment. The integration of the domains allowed for more centralized control over projects and better integration of HSI activities to scale. Comparable to the U.S. approach to HSI, the DND also uses MIL HBK 46855A (HFE), MIL STD 882D (SS). In addition, the DND uses CFITES (the standard for training development). In order to perform cost estimations for U.S. acquisition programs using Canadian data, these composite domains and their cost data will have to be decomposed.

The study identified three categories of savings in the 31 case studies. These categories can be applied to nearly all HSI cost estimation activities. These categories included immediate savings, extrapolated savings and uncalculated savings. These three measures provide a useful taxonomy that can be employed across the life cycle of any program. The article described immediate savings as items or resources that saved time and money during the work process. The extrapolated savings included those applications of HSI processes that occurred early in the life cycle, which led to decisions that saved money over time. The third, uncalculated savings, results from the impact of applying HSI rather than saving lives or improving operational effectiveness.

The methodical implementation of HSI activities within the Canadian DND involves several documents and activities, including: an HSI plan, Concept of Operations and Concept Support (CONSUP); Target Audience Descriptions (TAD); System Design Inputs; and System Evaluations. Human Factors Engineering (HFE) domain activities begin with a task analysis, and then mission, function and task decompositions (backbone of system safety assessments). Next, workload analysis and predictive studies are use to support the personnel domain requirements. Third, the results of the detailed task analysis are used to support training needs assessments, HHA assessments and SS assessments. Forth, the process focuses on trade-off analysis.

The results of the analysis in the report indicated that these projects used that HSI practices included 200 of the 400 modeling and simulation tools that were available. These tools included Human Form Computer Aided Drafting and Design (CADD) tools, prototyping, simulation tools, task network modeling (for workload analysis), and mission tools, as well as function and task analysis (MFTA) tools. Case studies focused on five areas of analysis. The Brooks et al. (2008) areas included:

- HSI program development: HSI program, Directorate of Technical Airworthiness support (DTA), Modeling and Simulation Coordination office definition, HSI Concept of Operations, TTCP HSI workshop
- Major HSI processes: Joint Intelligence information Capability (JIIFC), Advanced Land Fire Control System (ALFCS), Future Armored Vehicle System (FAVS), Multi Mission Effects Vehicle (MMEV), Maritime Helicopter Project, MHP modeling and workload, Very Short Range Air Defense (VSHORAD)
- HSI Process subset: Visual Acuity for divers, Grasshopper Uninhabited Aerial Vehicle (UAV); Canadian Patrol Frigate (CPF) Accommodation, Advanced Linked Extended Reconnaissance and Targeting (ALERT) Experimental Design Support)
- HSI tool evaluation: Helmet Mounted Display (HMD) for CF18, Clothe the Mounted Soldier (CMS) survey, Medium Logistics Vehicle Wheeled (MLVW) survey, Surveillance, Target Acquisition, Night Observation (STANO) survey and Collaborative Displays.

Provisions of HSI and project definition support: CB plus Program and performance projection framework, Cipro Plus requirements, Collaborative Planning and Management Environment (CPME), Directorate of Training and Education Programs, 3D modeling, Nuclear Biological Chemical Defense (NBCD) Repository Protection Program, Project Activity Reporting System (PARS) (Brooks, 2008).

Through pre-determined criteria, a comparison of case studies produced a likely range of budget percentages (4–20% HSI cost of the project engineering budget). An example of the budgetary considerations included the designing of "next generation" interfaces for fire control systems and experimental programs. These activities provided impact assessment for crew sizes and organizational structure. Developmental programs applied HSI costs, but they also considered to Commercial-off the Shelf (COTS) products. Humans Factor and Safety will impact COTS and system integration and will also affect the installation of the system. Program considerations were not the only concern. The subsequent paragraphs describe the reports discussion of the role of cost benefit analysis.

The report tracked the application of HSI cost benefits to determine a cost-benefit framework for the studies. The analysis included only calculable costs and savings. Of the five categories listed previously, only categories 2 and 3 were considered for the cost-benefit calculations. The other categories did not include immediate or extrapolated saving.

An example of a cost-benefit calculation included payback amounts produced by HSI applications. By removing unnecessary or redundant functionality early in the design process, significant savings can occur. For example, the removal of redundant displays resulted in $5,000,000 worth of savings (Brooks et al., 2010). If the payback or savings is substantial, the omission is a success. Uncalculated savings may occur when design changes positively impact the quality of life or the life expectancy of the Warfighter. These savings also impact safety and enable effective operations (Greenley & Associates, 2008). However, these costs were not used in a total cost-benefit analysis because of their multi-variant, circular and discountable characteristics. Future analysis should include these costs. The report suggests that if uncalculated savings can be estimated, there is the likelihood the cost savings would be in the range of millions of dollars.

The report follows the case study analysis with the methodology required to demonstrate the cost of HSI. The data produced budgetary percentages for HSI allocations. The percentages of HSI investment were consistent across projects. This result was regardless of the size of the program. The changes were a function of the HSI activities required by the program (i.e., human interface project complexity initiated increases in engineering budgets).

In conclusion, the DND report provides an alternative cost estimation methodology. It attempts to demonstrate a method for integrating the various domains of HSI. This is important because no process is a stand-alone process. Trade-off analysis must occur across the domains to correctly determine all estimation variables. While the report provides excellent information on immediate and extrapolated savings, it also mentions that uncalculated savings need to be analyzed more specifically which will result in exponential savings.

Liu (2009) explains the need for HSI cost measurement by examining Total Ownership Cost reduction in Development and Procurement stages of the life cycle. The programs of choice for this analysis were the Unmanned Aerial Systems (UAS). HSI, System Engineering and Program Manager costs were minimal compared to the one to five billion dollar RDT&E, O&M, Military Personnel (MILPERS) and Procurement budgets for the UAS programs examined. Liu described the current estimation method as a “Rule of Thumb” measure. This approach is based on the number of man-hours and the total engineering development. In the “Rule of Thumb” procedure, historical systems data influence the estimate. Factors that influence the cost estimate include expert opinion, technology changes, aircraft weights and number of units. The approach used in the article was parametric estimation methodology. This type of methodology incorporates size drivers such as number of requirements, interfaces, scenarios, algorithms and volatility factors. The method also uses effort multipliers (application factors, team factors, and schedule drivers). Together, the insertion of size drivers and effort multipliers into the Constructive Systems Engineering Cost Model (COSYSMO) modeling tool result in the total System Engineering effort.

To implement the model, the requirements are decomposed. The requirements decomposition should address the following:

- Determining the system of interest,
- Determining whether the requirements can be tested, verified or designed,
- Describing the relationship of the system of interest to the total system, and
- Assessing the number and the complexity of the requirements

Along with the requirements, the effort multipliers are established. There are 14 effort multipliers. These multipliers include issues such as understanding requirements and architecture, migration complexity, personnel, tool support, and many others. High-level integrated process teams provide these multipliers.

The article demonstrates the use of the model on HSI domain requirements that were pre-determined in government furnished documents. The author uses the COSYSMO model to describe national budget percentages for HSI activities. The author also provides suggested required inputs (variables/requirements specified earlier in this thesis), identifies useful outputs (identification of cost drivers, risk issues, and discrepancy warnings early in the program), and describes the model's application to pre-Milestone A related activities. The Liu (2009) article provides a better understanding of requirement impacts and an alternative cost estimation approach that appears to be more viable than the traditional methodology.

E. SUMMARY

In summary, sections (A) through (D) discussed the decision processes, concept models, and methodologies that are essential to formulate a new HSI cost estimation approach. HSI and cost estimation practitioners can use this approach for HSI activities throughout the acquisition life cycle and AoA. The following paragraph summarizes these sections.

Section (A) discussed the decision support system and the Life Cycle Management System HSI activities. This section addressed the HSI activities (and associated cost drivers) that occur across the acquisition life cycle. Section (B) investigated the basic cost estimation methods for performing estimates involving HSI criteria. The section discussed the Bratt et al. (1998) and Valerdi (2005) cost methodologies that emphasized HSI criteria adaptations of current cost methods in Occupational Health and System Engineering. These methods provided a resource to guide the HSI modification of current cost models and estimation methods. Section (C) described the Miller and Shattuck (2007) and the U.S. Air Force 711th Human Performance Wing (2006) HSI Models that will inform the new HSI cost estimation process developed in this thesis. Section (D) discussed reports by Canadian Defense Technology Center (2006), Brooks, et.al, (2008), and Liu (2009). These reports provide useful insights for determining a new method that will improve the cost estimation of HSI activities throughout the acquisition life cycle.

The literature review emphasized the need to identify calculated and uncalculated savings, direct and indirect costs, benefits, risks, and trade-offs as well as cost variables that are of particular interest to HSI cost estimation. These sections combined, provided the necessary background to develop the HSI activity database and cost models presented in the next section of this thesis.

An ultimate goal of HSI cost estimation will be the ability to perform parametric cost estimates with HSI historical costs (that are not currently available). Parametric cost methods, that use approved legacy system WBS, would then be treated as baselines that could then be incorporated into the estimates for funded requirements. The development of an HSI activity database is necessary to perform this type of estimate.

The next chapter introduces the first iteration of the proposed HSI Cost estimation process through development and verification of the HSI database and cost model. The chapter discusses the steps taken in developing the HSI activity database, followed by the initial SME Review verification studies. Next, the development of the HSI Cost model is discussed. Finally, the subsequent chapters discuss the recommendations for future verification, validation, and sensitivity analysis studies.

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III. METHOD

A. METHOD OVERVIEW

This thesis uses an exploratory research method to identify those HSI activities in the acquisition life cycle that should be considered when performing AoA cost estimations. A database of these activities provides a framework for future historical cost estimation processes. The study elicits Subject-matter experts (SMEs) feedback to determine the accuracy and supportability of the HSI activities in each of the life cycle phases. The feedback is then used to modify the HSI activity database for future validation studies, as well as to promote better cost estimation processes. Furthermore, the current HSI cost estimation methods are compared in terms of the variables they consider.

1. Participants

The Navy HSI Working Group and the Air Force HSI Office, in partnership with the Air Force 711th Human Performance Wing, supplied the SMEs for this study. The two pre-selected groups of SMEs were assigned a number (one through four) that corresponded to a life cycle phase. The assignments accounted for SME core competency areas when available (e.g., Requirements). Because the SMEs were participants *to* the research and were not subjects *of* the research, the Naval Postgraduate School's Institutional Review Board (IRB) determined this study was not human subjects research.

The activity review was designed to elicit many different viewpoints (i.e., holistic, domain specific). SMEs were identified as experts in HSI, an HSI domain, and/or in cost estimation. The study included 25 U.S. Air Force and 16 U.S. Navy respondents. The respondents' communities of practice and competency areas for the review were as follows (see Figures 18 and 19). The Navy respondents consisted of one military officer, 12 civil service employees, and 3 government contractors; the Air Force respondents consisted of one military officer, 15 civil service employees, and nine government contractors. Three Navy respondents provided cost estimation expertise. However, Air Force cost estimation experts were unavailable during the review period.

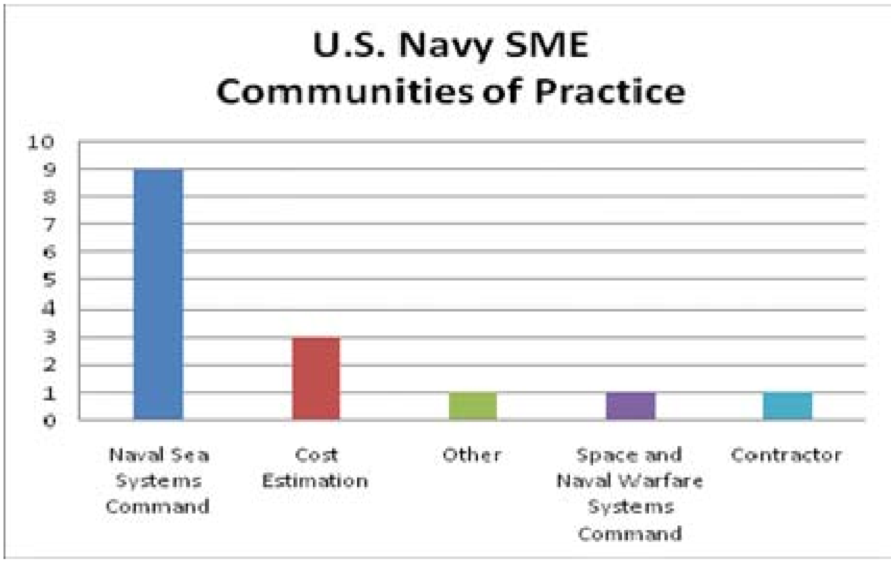


Figure 18. U.S. Navy Communities of Practice

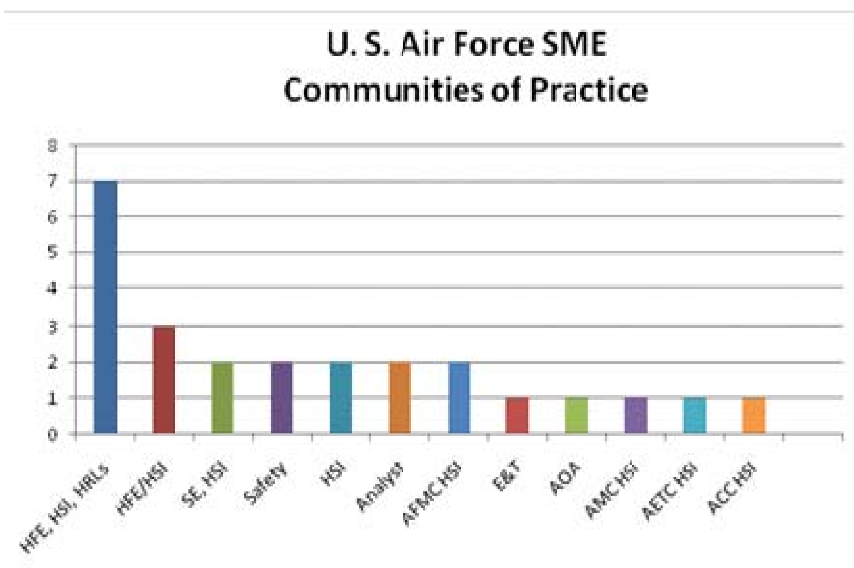


Figure 19. U.S. Air Force Communities of Practice

B. SME REVIEW MATERIALS

1. Database Development

A significant part of this thesis involved creating a database of HSI activities. The activities were extracted from research articles, government policies, and subject-matter experts. Comparison of existing cost estimation methods provided an additional source of HSI activities and cost drivers. After compilation of these activities, an initial database was developed (Database is available in NPS Electronic Storage).

The database to be use during the SME Review was designed as a Microsoft ® Access (HSI activity) database that was exported using a Microsoft ® Excel file format (see Figure 20).

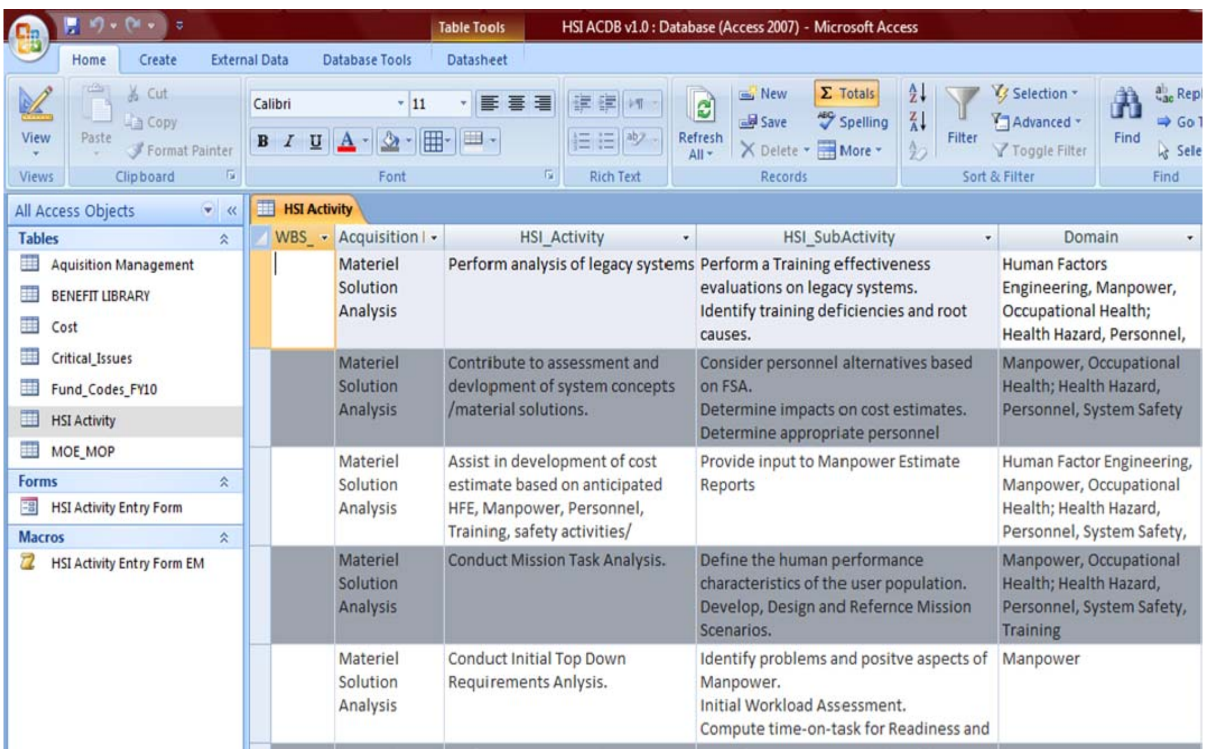
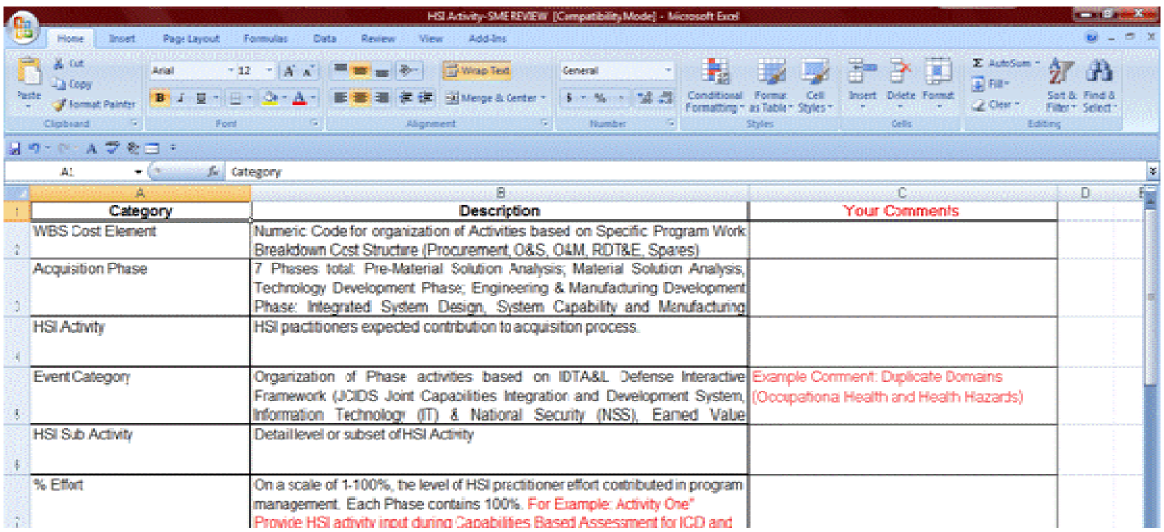


Figure 20. HSI Activity Access Database (excerpt)

2. SME Review Design

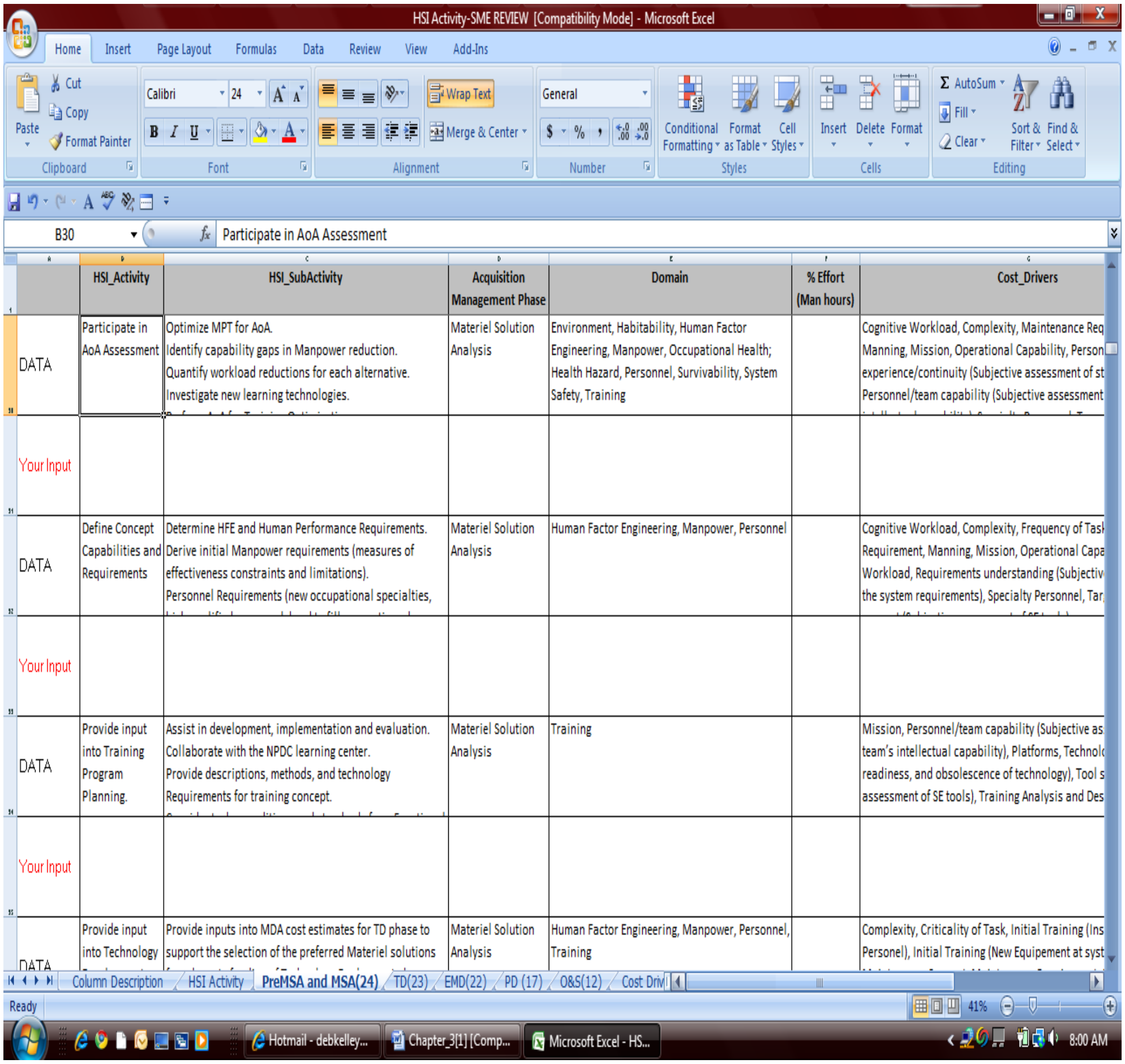
The SME review consisted of an Excel workbook containing three spreadsheets (i.e., Column Heading and Descriptions, Phase Activities, and Cost Drivers) (see Appendix C). The column description spreadsheet provided a proposed list of database column headings that were considered important to the cost estimation process (see Figure 21).



Category	Description	Your Comments
WBS Cost Element	Numeric Code for organization of Activities based on Specific Program Work Breakdown Cost Structure (Procurement, O&S, O&M, RDT&E, Spares)	
Acquisition Phase	7 Phases total: Pre-Material Solution Analysis; Material Solution Analysis, Technology Development Phase; Engineering & Manufacturing Development Phase: Integrated System Design, System Capability and Manufacturing	
HSI Activity	HSI practitioners expected contribution to acquisition process.	
Event Category	Organization of Phase activities based on IDTA&L Defense Interactive Framework (JCIDS Joint Capabilities Integration and Development System, Information Technology (IT) & National Security (NSS), Earned Value	Example Comment: Duplicate Domains (Occupational Health and Health Hazards)
HSI Sub Activity	Detail level or subset of HSI Activity	
% Effort	On a scale of 1-100%, the level of HSI practitioner effort contributed in program management. Each Phase contains 100%. For Example: Activity One" Provide HSI activity input during Capabilities Based Assessment for ICD and	

Figure 21. SME Review HSI Database Column Descriptions (excerpt)

The activity spreadsheet included 98 (major) life-cycle phase activities (MSA-24; TD-23; E&MD-22; P&D-17; O&S-12) and their corresponding sub-activities (see Figure 22). Additionally, the spreadsheet included potential HSI domains and cost drivers that affected each major activity.



	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	% Effort (Man hours)	Cost_Drivers
DATA	Participate in AoA Assessment	Optimize MPT for AoA. Identify capability gaps in Manpower reduction. Quantify workload reductions for each alternative. Investigate new learning technologies.	Materiel Solution Analysis	Environment, Habitability, Human Factor Engineering, Manpower, Occupational Health; Health Hazard, Personnel, Survivability, System Safety, Training		Cognitive Workload, Complexity, Maintenance Req Manning, Mission, Operational Capability, Person experience/continuity (Subjective assessment of st Personnel/team capability (Subjective assessment
Your Input						
DATA	Define Concept Capabilities and Requirements	Determine HFE and Human Performance Requirements. Derive initial Manpower requirements (measures of effectiveness constraints and limitations). Personnel Requirements (new occupational specialties,	Materiel Solution Analysis	Human Factor Engineering, Manpower, Personnel		Cognitive Workload, Complexity, Frequency of Task Requirement, Manning, Mission, Operational Capa Workload, Requirements understanding (Subjectiv the system requirements), Specialty Personnel, Tar
Your Input						
DATA	Provide input into Training Program Planning.	Assist in development, implementation and evaluation. Collaborate with the NPDC learning center. Provide descriptions, methods, and technology Requirements for training concept.	Materiel Solution Analysis	Training		Mission, Personnel/team capability (Subjective as team's intellectual capability), Platforms, Technolo readiness, and obsolescence of technology), Tool s assessment of SE tools), Training Analysis and Des
Your Input						
DATA	Provide input into Technology	Provide inputs into MDA cost estimates for TD phase to support the selection of the preferred Materiel solutions	Materiel Solution Analysis	Human Factor Engineering, Manpower, Personnel, Training		Complexity, Criticality of Task, Initial Training (Ins Personnel), Initial Training (New Equipement at syst

Figure 22. SME Review HSI Activity Spreadsheet (excerpt)

The final spreadsheet contained a generic cost driver list (see Figure 23).

Cost Drivers	
Cognitive Workload	Physical Workload
Complexity	Platforms)
Criticality of Task	Process capability (CMMI level or equivalent rating)
Difficulty of Task	Requirements understanding (Subjective assessment of the system requirements)
Documentation to match life cycle needs (Breadth and depth of required documentation)	Size
Frequency of Task	SLOC (Softw are lines of code)
Initial Training (Instructor & Key Personnel)	Specialty Personnel
Initial Training (New Equipment at system fielding)	Stakeholder team cohesion (Subjective assessment of all stakeholders)
Level of service requirements (Subjective difficulty of satisfying the key performance Parameters)	Target Audience
Maintenance Concept	Technology risk (Maturity, readiness, and obsolescence of technology)
Maintenance Requirement	Time Constraint for System Development
Manning	Tool support (Subjective assessment of SE tools)
Migration complexity (Influence of legacy system (if applicable))	Testing Type-detailed component testing
Mission	Testing Type-subsystem integration
Modeling & Simulation	Testing Type-system simulation and stimulation
Multisite coordination (Location of stakeholders and coordination barriers)	Testing Type-campaign or force-level (system of systems).
Occupational Training	Type
Operational Capability	Unit/Sustainment Field Training
Personnel experience/continuity (Subjective assessment of staff consistency)	Warranties
Personnel/team capability (Subjective assessment of the team's intellectual capability)	

Figure 23. SME Review Cost Driver List

Finally, a workbook was assembled that contained the Column Heading and Cost Driver spreadsheets, as well as one of the following phases: Materiel Solution Analysis, Technology and Development, Engineering & Manufacturing and Development, and combined Production and Deployment and Operation & Support.

3. Historical Data Collection

Historical system data also were collected from the Air Force Total Operational Cost (AFTOC) website, Defense Cost and Resource Center

(DCARC), and the ASN (RDA) website. These data were not included in the present study but could very well be used in future validation studies. The data included RDT&E product development, support, and test & evaluation costs, as well as O&S manpower, personnel, and training costs. The specific platforms for which data were available included the Predator (MQ-1), Global Hawk (RQ-4), and the Broad Area Maritime Surveillance Unmanned Aircraft System (BAMS).

C. SME REVIEW PROCEDURES

1. Distribution

The activity database review was administered via e-mail to pre-selected SMEs. Each participant received an introductory e-mail explaining the purpose and description of the review materials. Next, an e-mail containing the review materials and an instruction sheet was sent (see Appendix D). Respondents were asked to complete the review on or before a pre-determined due date (21 days later). Additionally, each respondent received a reminder e-mail midway through the review period.

2. Procedures

SMEs were required to review a selected (assigned) portion (a particular phase or phases) of the database and provide feedback. The review instructions were as follows. SMEs were required to review each spreadsheet to determine if the data were appropriate for AoA cost estimates. Next, SMEs were required to identify any data modifications (additions, deletions, corrections) that were required. Each spreadsheet provided blank rows for the SMEs to suggest missing activities. Furthermore, SMEs were asked to estimate the percentage of HSI man-hour effort required to complete the activity. SMEs were instructed that each of the phases was assigned a maximum value of 100% man-hour effort for a generic ACAT I program. Finally, SMEs were asked to provide an overall percentage of HSI man-hour effort for the entire phase.

Once the review was completed, the SMEs were instructed to save the document using an Excel (97-2003) format ("samefilename_yourinitials.xls" format) and to e-mail the results to the review administrator.

3. Coding Process

Table 14 illustrates the coding process implemented to classify database errors. Any data block that received a CR, INC or INCR code by the review administrator were modified in the next database increment.

Table 14. SME Review Codes

Code	Category	Explanation
AA	Additional Activity	SME added a recommended activity.
C	Correct	No (or) minimal correction needed (less than 20%). Corrections include spelling errors, word changes or activity item changes. The Percentage basis is the total number of words or activity action items.
CR	Correct with Recommendation	SME (or Review analyst) considers the activity correct and the SME provides a recommendation for activity adjustment (e.g., Split, re-sequence, roll-up 'include as second level to another activity').
E	% Effort*	SME provided man-hour effort percentage for HSI activity.
GC	General Comments	SME provided a question or statement that did not allow analyst to apply another code.
INC	Incorrect	Multiple corrections needed (greater than 20%). This percentage is based on number of words or activity items.
INCR	Incorrect with Recommendation	SME (or Review analyst) considers the activity incorrect and the SME provides a recommendation for activity adjustment (e.g., Split, re-sequence, roll-up 'include as second level to another activity').
NC	No Comment	SME did not respond or the SME has considered the data appropriate.
NQ	Not qualified	SME considered themselves inexperienced to comment on the activity.
R	Recommendation	SME provide a recommendation for correction of the activity components.

*Percent Effort was based on 100 % for each phase.

D. DEVELOPMENT OF HSI COST ESTIMATION MODEL

The HSI Cost Estimation Model development is based on all of the HSI activities that could contribute to a new cost estimation process. The model also combines previously validated models, cost variables, and cost drivers. The review administrator applied an (S) code to similar method components and a (DS) code for dissimilar components. The (DS) coded components were recommended for further review.

As stated during the review of the Valerdi's COSYSMO model (2005), a cost estimation model should be a function of System Engineering man-hour effort (see Chapter II, Figure 11). The cost estimation model for this thesis is based on the Valerdi model, but is a function of HSI effort and contains variables/drivers that are elicited from other methods and case studies (e.g., Canadian Defense methods and other HSI domain methods). The following section provides the review results and the proposed model.

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IV. SME REVIEW RESULTS

The SME Review method provided response rates, adjustment percentages, driver types and HSI-Effort percentages. The following sections describe these results.

1. Activity Review Results

Table 15 reports the overall response rate by type of respondent and total contact count (the number of SMEs that received the review).

Table 15. Total Response Rate

Total Contacts	83
Total Respondents	40
Overall % Response	48%
Total % Government Response (Military and Civil Service)	70%
Total % Contractor Response	30%

Table 16 contains the response rates by service and phase. The response rates ranged from 14% to 63%. The most responses were received for the MSA phase (63%), while the fewest responses were received for the TD phase (14%). Navy rate of return percentages were higher overall, however, had a smaller sample size (USN=15, USAF=25). The P&D and O&S phases resulted in the same rates of return (USN=57%; USAF=46%).

Table 16. Descriptive Response Rates

Phase	MSA		T&D		E&MD		P&D		O&S	
Phase #	1		2		3		4		5	
Service Group	USAF	USN	USAF	USN	USAF	USN	USAF	USN	USAF	USN
Total Phase Contacts	**14**	**8**	**14**	**6**	**15**	**6**	**13**	**7**	**13**	**7**
Total Government (GOV)	8	7	10	5	10	5	8	6	8	6
Total Contractor (CTR)	6	1	4	1	5	1	5	1	5	1
Total Respondents	**5**	**5**	**2**	**1**	**6**	**1**	**6**	**4**	**6**	**4**
Total GOV	3	4	2	1	3	1	4	3	4	3
Total CTR	2	1	0	0	3	0	2	1	2	1
% Total Response	**36%**	**63%**	**14%**	**17%**	**40%**	**17%**	**46%**	**57%**	**46%**	**57%**
% GOV Response	38%	57%	20%	20%	30%	20%	50%	50%	50%	50%
% Contractor Response	33%	100%	0%	0%	60%	0%	40%	100%	40%	100%

SME recommendations supported the accuracy of the database. Overall, the adjustments recommended ranged from 11% to 24% of the total number of entries for each phase. Table 17 provides a breakdown of the review phases, as well as the percentages of adjustments required. A data block is considered to be a single entry into the spreadsheet or database. The Total Activity Data Blocks column consists of the number of activities (i.e., the numbers in parentheses in the 1st column) multiplied by six (the number of columns in the database). The Total Coded Responses consists of the Total Activity Responses multiplied by six (i.e., the number of columns in the database).

Table 17. Database Descriptive Breakdown and Accuracy Rates

Acquisition Phase (# Activities)	Total Activity Responses	Total Activity Data Blocks	Total Coded Responses	Total Adjustments Required	Percentage Adjustment Required
MSA (24)	154	144	924	183	20%
T&D (23)	39	138	234	57	24%
E&MD (22)	82	132	492	53	11%
P&D (17)	60	102	360	74	21%
O&S (12)	27	71	162	19	12%

Table 18 provides a breakdown of the Total Coded Responses (from Table 17) by coding category and phase. Table 18 also provides additional detail with respect to the Total Adjustments Required column (in Table 17). The numbers in this column (of Table 18) are based on the following coding categories: Correct with Recommendation (CR); Incorrect (INC); Incorrect with Recommendation (INCR); or, General Comment (GC). The Percentage Adjustment Required (PAR) results consisted of dividing the Total Adjustments Required datum by the Total Coded Responses.

Table 18. Activity Code Breakdown by Phase

	NC	E	C	CR	GC	NQ	INC	INCR
MSA	464	103	167	90	42	5	2	49
T&D	82	46	49	32	2	0	0	23
E&MD	299	44	96	25	9	0	0	19
P&D	163	34	89	36	26	1	0	11
O&S	69	23	51	6	12	0	0	1

NC=No Comment
E= Effort Given
C=Correct
CR= Correct w/Recommendation
GC=General Comment or Question
NQ=Not Qualified to comment
INC=Incorrect
INCR=Incorrect w/Recommendation

2. Database Column Review Results

SMEs were asked to review the database columns to determine whether they would provide the appropriate information necessary for establishing a historical cost database for HSI activities. Each SME reviewed 19 data blocks. Tables 19 and 20 provide the response rates and coding categories for this review (see Appendix C for a full listing of columns and descriptions). Overall, the database columns received positive reviews. SMEs considered all columns useful for establishing a historical database in support of HSI cost estimation activities. The data blocks that required adjustments (30%) were the based on SME general comments (GC) or recommendations (CR) for enhancements to the database.

Table 19. Database Column Response Rate

Total Participants	13
Total Responses	124
Total Data Blocks	19
Total Coded Comment Blocks	244
Total Adjustment RQD	72
Percentage Adjustment RQD	30%

Table 20. Column Coding Categories

C	CR	INCR	INC	NC	NQ	GC
51	43	0	0	120	1	29

3. Cost Driver Section Review

The following list provides the results from the review of the cost drivers. SMEs commented on the accuracy of the proposed cost drivers and classified them by cost type (i.e., (D)irect or (I)ndirect). Overall, the list of cost drivers appeared to be adequate. However, some SMEs noted that certain drivers were specific to HSI activities while other drivers could be applied to many other acquisition activities. Respondents suggested that three drivers be removed (Size, Platform and Type). One of these drivers (type), however, was acceptable upon correction to the term system type.

Cost Driver Results List

(I) Cognitive Workload
(I) Complexity
(I) Criticality of Task
(I) Difficulty of Task
(I) Frequency of Task
(I) Level of service requirements (Subjective difficulty of satisfying the key performance Parameters)
(I) Mission
(I) Modeling & Simulation
(I) Multisite coordination (Location of stakeholders and coordination barriers)
(I) Personnel experience/continuity (Subjective assessment of staff consistency)
(I) Personnel/team capability (Subjective assessment of the team's intellectual capability)
(I) Physical Workload
(I) Process capability (CMMI level or equivalent rating)
(I) Requirements understanding (Subjective assessment of the system requirements)
(I) Stakeholder team cohesion (Subjective assessment of all stakeholders)
(I) Target Audience
(I) Technology risk (Maturity, readiness, and obsolescence of technology)
(I) Time Constraint for System Development(I) Tool support (Subjective assessment of SE tools)
(D) Documentation to match life cycle needs (Breadth and depth of required documentation)
(D) Initial Training (Instructor & Key Personnel)
(D) Initial Training (New Equipment at system fielding)
(D) Maintenance Concept
(D) Maintenance Requirement
(D) Manning
(D) Migration complexity (Influence of legacy system (if applicable))
(D) Occupational Training
(D) Operational Capability
(D) SLOC
(D) Specialty Personnel
(D) Testing Type-detailed component testing
(D) Testing Type-subsystem integration
(D) Testing Type-system simulation and stimulation
(D) Testing Type-campaign or force-level (system of systems)
(D) Unit/Sustainment Field Training
(D) Warranties

In addition to the classification of the listed drivers, the SMEs provided additional drivers as seen in the following list. The list was further classified by the administrator to include cost type (i.e., direct (D) or indirect (I)) based on the Federal Accounting Regulations classification process.

(D) Facilities - Development and test
(D) Facilities: Operations and maintenance
(D) Facilities: Training infrastructure
(D) Force Structure Composition (Active, Reserve, Officer, Enlisted, Civilian, Contractor)
(D) Safety requirements and regulations
(D) Special tools & equipment: development;
operations and maintenance
(D) Specialized tools required for maintenance
(D) Training location
(I) Habitability shortfalls that lead to workforce attrition
(I) Accessibility
(I) Complexity (sub-categories): technological complexity & organizational complexity
(I) Configuration and Change Management
(I) Consequence of errors
(I) COTS and GOTS suitability assumptions
(I) Errors identified
(I) Facility layout (communication, distance to amenities, distance from noise source)
(I) Function allocation (human, machine, supervisory, manual)
(I) Intuitive usability (can novices operate without any training)
(I) Material selection
(I) Modeling & Simulation Validation
(I) Poor Situation Awareness
(I) Poor usability
(I) Required KSAs
(I) Requirements Determination
(I) Situational awareness of automation state
(I) Specialized safety
(I) Specialty Personnel (development)
(I) Team design
(I) Test safety
(I) Training Analysis and Design
(I) Training pipeline (or other training "time" metric)
(I) Under-manning

4. HSI Effort Results

The final analysis consisted of looking at percentages of HSI-Effort across the life cycle phases for a general ACAT I program. The results in the following sections are intended to provide a starting point or baseline for HSI costs. The results in Tables 21 through 25 are ordered according to the acquisition cycle phases. A paper format precludes presentation of the entire database. Therefore, the tables show only the first two lines of each row. A complete database is available in electronic format upon request. Additionally, each table displays the total number of SME participants for each phase. Furthermore, the data presented in these tables is non-normalized.

Table 21 provides the Materiel Solution Analysis Phase HSI-Effort results. Pre-Materiel Solution Analysis (or Pre-Materiel Development Decision) activities were provided an event coding of (A) through (F) while the Materiel Solution Analysis activities are coded (G) through (S). The results ranged an average of 3% to 28% for the various activities. In other words, SMEs estimated these activities would represent between 3% and 28% of the total (i.e., 100%) HSI effort for the MSA phase. The highest HSI activity percentages were reported for the following activities:

- Provide HSI activity input during Capabilities Based Assessment for ICD (M=23%, SD=0.20);
- Provide an HSI assessment based on the best available solution descriptions (in CBA, AoA, Study Guidance, ICD) across all HSI domains and to define the risk level in each. (M=28%, SD=0.21);
- Provide a total system analysis based on functional relationship perspectives with an emphasis on system boundaries (M=13%, SD=0.11); and,
- Participate in the AoA assessment (M=10%, SD=0.02).

Furthermore, USN reviewers suggested combining the domains of Environment, Occupational Health and Safety while USAF reviewers replaced Occupational Health with Health Hazards.

Table 21. MSA HSI-Effort Percentage (based on input from 10 SMEs)

Event	HSI_Activity	MEAN % Effort (Based on	STDV
A.	Provide HSI activity input during Capabilities Based Assessment for ICD	23%	0.20
B.	Provide HSI input into the HSIP section of the System Engineering Plan (SEP)	8%	0.03
C.	Provide a total system analysis based on functional relationship perspectives with an emphasis on system	13%	0.11
D	Provide HSI considerations into the AoA Study plan	3%	0.02
E.	Provide HSI input into ESOH Integration Strategy.	6%	0.04
F.	Perform HSI assessments based on best available solution description (in CBA, AoA, Study Guidance, ICD) across all	28%	0.21
E.	Perform an HSI analysis of legacy systems with respect to each domain and addressed to potential integrated impact	8%	0.04
F.	Contribute to assessment and development of system concepts /Materiel solutions.	4%	0.01
G.	Assist in development of cost estimate based on anticipated HFE, Manpower, Personnel, Training, safety activities/	4%	0.01
H.	Conduct Mission Task Analysis.	7%	0.04
I.	Conduct a Initial Top Down Requirements Analysis.	8%	0.02
J.	Assist in performance of Manpower /Personnel alternatives and concept development and assessments	4%	0.01
K.	Identify Manning needs, manpower lessons learned, and high drivers from legacy systems.	4%	0.02
L.	Assist in linear modeling and studies analysis of system approach alternatives.	7%	0.02
M.	Conduct Manpower/Training assessments to determine KPPs learning objectives and training requirements for	6%	0.04
N.	Assist in deriving systematic prediction of conditions through Initial Safety, and Occupational Health requirements and	4%	0.01
O.	Participate in AoA assessment	10%	0.02
P.	Define concept capabilities and requirements	3%	0.02
Q.	Provide HSI input into Technology Development Strategy	3%	0.00
R.	Provide HSI Input into Life Cycle Sustainment Plan.	4%	0.02
S.	Provide HSI input into Support System Engineering Technical Reviews (SETRs)	3%	0.01

Tables 22 and 23 provide the HSI Effort for the Technology Development phase. For this phase, SMEs estimated these activities would represent between 3% and 20% of the total (i.e., 100%) HSI effort. Several of the activities that are listed (callout/ guide or new activities suggested by SMEs) have only one SME effort contribution. These values have a standard deviation of zero.

The highest HSI Effort percentages were attributed to the following activities:

- Determine the need for an HSI IPT or working group (M=20%, SD=0.00),
- Demonstrate & validate System & Technology maturity versus defined user needs & environmental constraints (M=20%, SD=0.00)
- Decompose functional definitions into Critical Component Definitions & Technologies Verification Plan (M=16%, SD=0.00)
- Demonstrate enabling/critical Technology components versus plan (M=13%, SD=0.08),
- Perform analysis and recommendations for system technology development (M=12%, SD=0.12),
- Provide HSI input into the Capability Development Document and Acquisition Baseline (M=11%, SD=0.08; M=11%, SD=0.08), and
- Conduct formal development of human-centered source selection criteria for RFPs at Milestone (MS) A (M=11%, SD=0.13).

Table 22. Technology Development Phase HSI Effort (based on input from three SMEs)

EVENT	HSI_Activity	MEAN Activity Effort	SD
GUIDE	Review all the inputs to the Technology Development Phase including the following:	20%	(one value)
A. New Activity	Determine the need for an HSI IPT or a working group	20%	(one value)
B.	Establish a HSI IPT or Working Group - consistent with the size and complexity of the envisioned acquisition program	10%	0.03
GUIDE	Throughout the next 5 steps C-G conduct trade offs and support the AoAs with the identified sub activities.		
C.	Determine all relevant Critical Operational Issues and determine and develop Measures of Effectiveness	5%	0.01
D. Callout	Develop System Performance (&Constraints) Specification & Enabling/Critical Technologies & Prototypes Verification	10%	(one value)
E. Callout	Develop Functional Definitions for Enabling/Critical Technologies/Prototypes & Associated Verification Plan	10%	(one value)
F. Callout	Decompose functional definitions into Critical Component Definition & Technologies Verification Plan	16%	(one value)
G.	Identify HSI technical risks and mitigation strategies for technology development.	10%	(one value)
GUIDE	Throughout the next 7 Steps H-O conduct trades that are spread across the identified sub activities.		
H.	Demonstrate enabling/critical technology components versus plan	13%	0.08
I.	Provide integrated HSI assessment methodology for technology down selection recommendations and use in full	7%	0.05
J.	Refine and update requirements	10%	0.00
K.	Assist in technology selection	7%	0.05
L.	Perform analysis and recommendations for system technology development.	12%	0.12
M.	Assist in development of System Functional Specs & Verification Plan to evolve system functional baseline	6%	0.06
N.	Participation in Integrated Test Team (ITT) and Evaluation or other Integrated Performance Team IPT as may be	8%	0.03

Table 23. Technology Development Phase HSI Effort (continued)

EVENT	**HSI_Activity**	**MEAN Activity Effort**	**SD**
Guide	Throughout the next 7 Steps P-S conduct trades that are spread across the identified sub activities.	20%	(one value)
P. Callout	Demonstrate enabling/critical technology components versus plan	16%	(one value)
Q. Callout	Demonstrate system & prototype functionality versus plan	10%	(one value)
R. Callout	Demonstrate/model integrated system versus performance specification	10%	(one value)
S. Callout	Demonstrate & validate system & technology maturity versus	20%	(one value)
GUIDE	Insure the production and completion of inputs to the following products:		
T.	Review and provide input into Preliminary design and allocation baseline.	8%	0.10
U.	Provide HSI input into the Capability Development Document	11%	0.13
V.	Provide input into the Acquisition Strategy for goals, objectives and entrance and exit criteria as a member of	3%	0.03
W.	Provide input into Acquisition Program Baseline (APBs)	11%	0.13
X.	Incorporate requirement for contractor generated HSIP(s) and associated source selection criteria in Request for	8%	0.03
Y.	Conduct formal development of human-centered source selection criteria for RFPs at Milestone (MS) A	11%	0.13
Z.	Apply analysis in findings to Test and Evaluation Strategy (TES), LCMP and TEMP	6%	0.06
AA.	Provide input into System Engineering Review process (SRR).	7%	0.04
BB	Provide input into System Engineering Review process (SFR)	10%	(one value)
CC	Provide input into System Engineering Review process (PDR)	16%	(one value)

Table 24 provides the HSI Effort for the Engineering and Manufacturing Development Phase. The results for these activities ranged from 2% to 8% of the total HSI effort. Activities that resulted in the same percentage contributions (i.e., 5%,5%, 5%) display a standard deviation of zero. The HSI activities with highest effort percentages included:

- Assisting in development of test plans for integrated system testing (*M*=8%, *SD*=0.03); and,
- Providing HSI input into technical reviews and Systems Engineering activities (*M*=8%, *SD*=0.04).

SMEs suggested moving two activities from the MSA phase to the TD phase. These activities pertained to proving HSI input into the draft CDD and the Training Program Plan.

Table 24. E&MD Phase HSI Effort (based on input from seven SMEs)

Event Category	HSI_Activity	MEAN % Effort	SD
A.	Provide HSI input to the TEMP	5%	0.00
B.	Finalize HSI Requirements by obtaining agreement from	2%	0.01
C.	Assist in development of detailed design requirements	7%	0.02
D.	Assess detailed system designs to ensure that they	4%	0.02
E.	Participate in prototypes/test materials development (for	5%	0.04
F.	Evaluate prototypes (or test materials) for HSI Criteria	New Activity	
G.	Participate in Design Demonstrations (to include	6%	0.03
H.	Evaluate HSI criteria for the system during component /	5%	0.00
I.	Perform HSI evaluation on System Components	4%	0.02
J.	Assist in Development of Test Plans for integrated system	8%	0.03
K.	Participate in HSI test events	6%	0.02
L.	Participate in ECP development	3%	0.02
M.	Provide HSI updates to Acquisition Strategy and	2%	0.01
N.	Provide HSI input into Capability Production	4%	0.01
O.	Provide HSI input into technical reviews and Systems	8%	0.04
P.	Provide HSI input for error and fault analysis	3%	0.01

Table 25 provides the HSI Effort for the Production and Development phase. The events coded (A) through (N) ranged from an average of 4% to 10% of the total HSI effort. The highest HSI effort percentages were reported for the following activities:

- Test and Evaluation support and participation (LFT&E) (*M*=10%, *SD*=0.07);
- Assisting with the System Hazard Analysis (SHA) and Operating and Support Hazard Analysis (*M*=8%, *SD*=0.04); (*M*=13%, *SD*=0.11); and,
- Participate in the AoA Assessment (*M*=10%, *SD*=0.02).

SMEs suggested the insertion of three additional activities.

Table 25. Production and Deployment Phase HSI Effort (based on input from 10 SMEs)

Event	HSI_Activity	Mean Activity Effort (% Man Hours)	SD
A.	HSI Planning and	5%	0.01
B.	Review and Develop HFE	7%	0.04
C.	Verify HSI requirements for	4%	0.01
D.	Assist in T&E HSI analyses of system design and installation	7%	0.02
E.	Assist in T&E HFE analyses of system design and installation	6%	0.01
F.	T&E support and participation	6%	0.03
G.	T&E support and participation (LFT&E)	10%	0.07
H.	T&E support and participation (FOT&E)	7%	0.02
I.	Review OPTEVFOR reports	5%	0.00
J.	Document and analyze post deployment lessons learned	5%	0.01
K.	Provide input into Review process for P&D Phase	4%	0.02
L.	Update Manpower/Personnel requirements for system	6%	0.01
M.	Update Training systems requirements for system	6%	0.00
N.	Assist with System Hazard Analysis (SHA)and Operating	8%	0.04

Table 26 provides the HSI-Effort contributions for the Operation and Support phase. The results for activities (A) through (K) ranged from 5% to 15% of the total HSI effort. The highest HSI activity percentages reported for the activities included:

- Provide Follow-on Test and Evaluation support (*M*=15%, *SD*=0.07); and,
- Provide testing and verification of Follow-on Test & Evaluation processes (*M*=12%, *SD*=0.03).

SMEs suggested incorporating two of the original database activities into activities that pertained to additional Manpower or HFE support during Full Operational Capability Support. SMEs did not remove any HSI activities from the database but did add one activity (HSI planning and management).

Table 26. Operation and Support Phase HSI Effort (based on input from 10 SMEs)

Event	HSI_Activity	MEAN % Effort (Man hours)	ST DEV (% EFFORT)
A.	HSI Planning and Management	8%	New Activity
B.	Provide Follow-on Test and Evaluation support	15%	0.07
C.	Provide analysis for HFE FOC support and	8%	0.01
D.	Provide recommendations for HFE FOC support and	8%	0.03
E.	Provide Training FOC support and logistics/sustainment	9%	0.01
F.	Provide Manpower/Personnel FOC support and	6%	0.01
G.	Analyze and prototype post-product improvements for the	7%	0.02
H.	Provide input for sustainment of operational readiness and	7%	0.04
I.	Provide testing and verification of Follow-on T&E processes.	12%	0.03
J.	Provide FOC support and logistics/sustainment	8%	0.03
K.	Provide input into O&S review processes (ISR)	5%	0.01

5. Results Summary

The SME Review provided results that included the Descriptive and Total Response Rates, Database Adjustment Rates, Cost Driver use and type determination and HSI-Effort.

This thesis returned an overall response rate by service and type of respondent. The most of the responses occurred during the MSA phase (63%), while the fewest responses were received for the TD phase (14%). Overall, the adjustments recommended ranged from 11% to 24%. The most adjustments occurred during the TD phase (24%), while the E&MD phase received the fewest adjustments (11%).

The second results section pertained to the HSI activity database columns that are required to establish a HSI/cost estimation database. The SMEs considered all columns were useful for establishing a historical database in support of HSI cost estimation activities.

The third section of results pertained to review of cost drivers. These results provided an identification of drivers (type) as well as 33 additional drivers that can attribute to an HSI cost estimation process.

Finally, the SMEs provided HSI-Effort percentages of the life cycle phases for a general ACAT I program. These results are intended to provide a starting point or baseline for HSI costs. The HSI-Effort (out of 100%) results included the following percentage ranges: MSA (3-28%), TD (3-20%), E&MD (2-8%), P&D (4-10%), and O&S (5-15%). The remainder of this thesis discusses these results in more detail as well as provide recommendations for future work.

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V. DISCUSSION

The purpose of this thesis was to develop a qualitative method for determining HSI-specific costs that can be used for conducting tradeoffs during the AoA. The effort was necessary to improve the accuracy of cost estimates over the life cycle of the system and to provide a basis for a new HSI cost estimation process. The method produced an HSI activity database, HSI cost drivers and an HSI level of effort for every acquisition life cycle phase for a generic ACAT I program (See Appendix C). SMEs provided the requisite knowledge for refining the database. The following sections discuss the qualitative findings.

A. RESPONDENTS

Although the sample size was small, the range of SME competency areas provided a diverse view of the HSI cost processes. HSI is a relatively young discipline with few SMEs. The small pool of SMEs (who tend to be in high demand and are typically overworked) may have contributed to the somewhat low response rate of approximately 48%. Other factors that contributed to the response rate included availability, unfamiliarity with phase assignment, and confusion concerning what was expected of the SME.

Response rates varied within and between services for several reasons. For example, USAF SMEs were reassigned during the review and were unable to complete their assessment of the database. In these cases, respondents were encouraged to provide as many recommendations as time permitted. Therefore, analyses were based on individual data item entries instead of individual responses.

Every attempt was made to match a SME’s expertise to the appropriate acquisition phase. However, some SMEs reported they were unfamiliar with the HSI activities within the acquisition phases to which they were assigned. In these cases, when SMEs appealed to the review administrator, they were offered an alternate phase to review. Respondents also gave domain viewpoints (i.e., training, manpower) as well as holistic viewpoints.

B. HSI ACTIVITY DEVELOPMENT

The HSI database responses provided validation of the activities needed to perform cost estimations. During the HSI activity evaluation, SMEs emphasized balancing the results of this study of the activities found in the system engineering process and human view frameworks. Additionally, SMEs suggested that future efforts should clarify HSI activities in the Acquisition Management, Acquisition Engineering and Support/Sustainability activity tiers. This clarification would necessitate determining “areas of responsibility” within the HSI domain practitioner community. SMEs also stated that HSI work was usually taken “out of hide” and that HSI work is often dismissed or not considered. For example, manpower authorizations determined by knowledgeable practitioners have not been properly considered during trade-off deliberations. Other SME suggestions included adding items to the database such as “Establishing a need for HSI involvement in an IPT” and “HSI planning and management” elements.

Another finding pertained to the specificity of some database items. SMEs suggested that some activities contained an excessive amount of details. This may have been true for some activities. However, some HSI processes need to be described in detail so that the nature of the activity is truly understood. For example, modeling & simulation activities or specialized HSI tools may be needed in some types of analyses. If these activities and tools are not specified, the associated cost elements will not be accurate; they may be underestimated significantly.

The SMEs also suggested including activities such as participation in technical information meetings (in the E&MD phase) and contributing to contractor taskings. Contractor tasking is a controversial and obscure cost issue. Since contractors perform many of the HSI activities, contracts should include indirect costs for these personnel as stated in DTM-09-007 (2010).

Overall, the data collected from the SMEs supported the use of the proposed HSI database for AoA and Test & Evaluation cost estimation processes. Although the TD Phase returned the fewest responses, it was the most informative for AoA guidance. The SMEs elaborated on activities regarding AoA trade-off studies and suggested assessment activities that were integrated across HSI domains. These activities demonstrate the need for a significant level of HSI practitioner involvement. Test & Evaluation activities were also expanded to include demonstration, validation and verification processes.

C. DATABASE COLUMNS

The database column review resulted in many positive comments from the SMEs. They agreed that all proposed data elements were informative for HSI cost purposes. However, they recommended that the "Event/Category" column be refined by using a cost tier structure to organize the activities. One SME suggested that program IPTs tend to focus on WBS level II and III tiers but that cost estimation becomes increasingly difficult at these levels because of the detail inherent in these tiers. It may not be feasible to perform cost estimation for HSI activities at the WBS tier III during the AoA. It may be that the tier III level of analysis will have to wait until later in the acquisition process.

D. COST DRIVERS

The cost driver evaluation included a general list of drivers identified during the literature review. These drivers consisted of typical HSI domain, cost method and System Engineering driver elements. The SMEs reported that the cost drivers were appropriate for an HSI cost database. Although, the cost driver list was intended for HSI activities, SMEs suggested that several of the driver elements could be used in activities unrelated to HSI (e.g., configuration management, SLOC). SMEs also classified the cost drivers as either direct or in direct and assigned cost drivers to each activity.

Having the SMEs assign cost drivers to various activities seemed to be a viable approach to cost estimation. However, the SMEs indicated that costs rarely fit into such neat packages. In spite of this, the SMEs were able to validate the potential drivers for specific activities.

E. HSI EFFORT

The HSI Effort data provided the final (and most interesting) findings for the AoA cost estimation. SMEs provided HSI effort for overall phase to which they were assigned, either as a percentage of total effort or as the number of man-hours required. SMEs indicated that the most HSI activity should occur during the MSA phase. SMEs also suggested that the HSI participation as a whole (within the MSA phase) attributed to approximately 40-60% of effort (out of 100%) of a general ACAT I program. Within the MSA phase, HSI Effort for individual activities ranged from 1% to 28%. Those SMEs who expressed HSI participation in terms of man-hours provided some interesting insights. Examples of these man-hour estimates included:

- Provide HSI Assessment based on best available solution description (in CBA, AoA, Study Guidance, ICD) across all HSI domains to define level of risk in each: 1000 hours.
- Participate in AoA Assessment: 500 hours.
- Perform an HSI analysis of legacy systems with respect to each domain and address the potential integrated impact and associated risks: 500 hours.

Other findings suggested that ACAT I programs were multiyear efforts, and SMEs found it difficult to assess the individual activities across multiple years and multiple increments.

VI. RECOMMENDATIONS FOR FUTURE WORK AND CONCLUSION

A. RECOMMENDATIONS

The thesis explored HSI cost activity development for the AoA process of a generic ACAT I program. It also provides an initial database that contains the HSI activities that should be included in the cost estimation process. The thesis focused on cost estimation in support of the AoA but considered HSI activities that span the entire acquisition life cycle. Based on the results and analysis reported herein, the following recommendations are made for future work.

Identify the most important HSI activities in each of the oversight documents, including the following: Review Acquisition Strategy; Acquisition Plan; Source Selection Plan; RFP; Final Product Baseline; Critical Safety List Items; PESHE; and TEMP.

- Perform HSI cost method comparisons in order to develop variables for a cost model;
- Clarify HSI activities in the Acquisition Management, Acquisition Engineering and Support/Sustainability activity tiers.;
- Organize the database in terms of work breakdown structure cost elements;
- Identify the benefits/impacts and risk/cost relationships of HSI activities;
- Determine domain tradeoffs that must occur to achieve accurate cost estimates or the AoA; and,
- Use a system of interest to in a case study approach to verify the database.

Unfortunately, most programs do not contain HSI cost data. Therefore, a majority of HSI cost estimates will have to rely, at least initially, on “rule of thumb” or heuristic approaches. Two programs that are making a concerted effort to document HSI costs are the MQ-1 and LCS. These programs should provide HSI cost data that can be used in a parametric cost estimation approach. The parametric approach to estimating HSI costs is the ultimate goal.

B. CONCLUSION

Cost estimation is an amalgamation of systems that helps ensure the validity, reproducibility and affordability of any defense acquisition program. Capability assessments allow comparisons with benchmark resources (current or legacy system capabilities and costs). The resultant cost data can then be applied to the estimation of costs for future systems as early in the acquisition process as the AoA. This thesis was intended to be general in nature so that it can be applied to any military service and to any type of system. The research effort emphasized issues such as development/operation test and evaluation processes, program increments, operation and support, and environmental costs. This method will allow HSI practitioners and other professionals the ability to assess the level of HSI effort required for an acquisition program and to mitigate potential risks and uncertainties that may adversely impact the acquisition of systems. The goal is to provide the best possible system to the Warfighter that is also cost effective and timely. This thesis is an important step in that direction.

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APPENDIX A. COMPOSITE STANDARD PAY CHARTS AND REIMBURSEMENT RATES

MILITARY COMPOSITE STANDARD PAY AND REIMBURSEMENT RATES
DEPARTMENT OF THE AIR FORCE
FOR FISCAL YEAR 2011 [1/]

MILITARY PAY GRADE	AVERAGE BASIC PAY	ANNUAL DOD COMPOSITE RATE [2/]	ANNUAL RATE BILLABLE TO OTHER FEDERAL AGENCIES [3/ 4/]
O-10	$181,587 [5/]	$300,725	$305,184
O-9	181,587	305,777	310,236
O-8	160,654	273,032	277,491
O-7	139,237	246,184	250,643
O-6	115,447	214,027	218,486
O-5	93,313	182,049	186,508
O-4	78,866	160,639	165,098
O-3	63,403	136,217	140,676
O-2	48,814	110,344	114,803
O-1	34,673	87,651	92,110
WO-5	----	----	----
WO-4	----	----	----
WO-3	----	----	----
WO-2	----	----	----
WO-1	----	----	----
E-9	$72,291	$137,410	$141,869
E-8	58,494	116,749	121,208
E-7	49,755	104,179	108,638
E-6	40,444	90,069	94,528
E-5	32,353	76,538	80,997
E-4	25,667	63,428	67,887
E-3	21,021	50,452	54,911
E-2	19,727	46,434	50,893
E-1	16,900	41,007	45,466
CADETS	$11,654	$16,793	Not applicable

Notes:

/ Effective fiscal year 2005, military personnel services for Foreign Military Sales (FMS) shall be priced using the Composite Rates that already include permanent change of station (PCS) expense and shall no longer use the actual PCS expense for PCS moves to support a FMS case. Effective FY 2006, the military personnel services for FMS shall be priced using the DoD Composite Rate plus the acceleration factor shown in Tab K-1. Reimbursement of the acceleration factor shall be deposited into the Defense Health Program (97*0130). Reimbursement of the per capita normal cost for Medicare-eligible retiree health care (MERHC) accrual shall be deposited into the Miscellaneous Receipts Account 3041. The next update of the DoD FMR Vol. 15 Section 070203 will reflect these change.

/ The annual DoD composite rate includes the following military personnel appropriation costs: average basic pay plus retired pay accrual, Medicare-eligible retiree health care (MERHC) accrual, basic allowance for housing, basic allowance for subsistence, incentive and special pay, permanent change of station expenses, and miscellaneous pay. **Includes** a per capita normal cost of $5,673 for MERHC accrual -- **see Tab K-1**.

/ The annual rate billable to Other Federal Agencies recovers additional military related health care costs financed by the Defense Health Program. The annual billable rate includes an acceleration factor of $10,132 for all personnel. **Excludes** per capita normal cost of $5,673 for MERHC accrual -- **see Tab K-1**.

/ To compute a Daily Rate, apply a factor of .00439. To compute an Hourly Rate, apply a factor of .00055.

/ Basic pay for these officers is limited to the rate of basic pay for Level II of the Executive Schedule, which currently is $181,587 per year.

Tab K-5

Figure 24. (From "Air force military composite standard pay and reimbursement rates," 2010)

MILITARY COMPOSITE STANDARD PAY AND REIMBURSEMENT RATES
DEPARTMENT OF THE NAVY
FOR FISCAL YEAR 2011 1/

MILITARY PAY GRADE	AVERAGE BASIC PAY	ANNUAL DOD COMPOSITE RATE 2/	ANNUAL RATE BILLABLE TO OTHER FEDERAL AGENCIES 3/ 4/
O-10	$181,587 5/	$291,527	$295,986
O-9	181,587	293,387	297,846
O-8	161,619	267,571	272,030
O-7	139,396	238,269	242,728
O-6	117,298	218,288	222,747
O-5	94,425	187,883	192,342
O-4	79,869	169,549	174,008
O-3	65,118	144,700	149,159
O-2	51,126	113,231	117,690
O-1	37,874	90,901	95,360
WO-5	$95,112	$182,380	$186,839
WO-4	82,822	157,931	162,390
WO-3	70,047	140,858	145,317
WO-2	57,958	123,935	128,394
WO-1	----	----	----
E-9	$71,210	$140,175	$144,634
E-8	56,707	119,669	124,128
E-7	47,527	105,918	110,377
E-6	39,346	92,856	97,315
E-5	31,585	79,826	84,285
E-4	25,354	67,296	71,755
E-3	21,516	55,557	60,016
E-2	19,676	50,071	54,530
E-1	17,122	44,599	49,058
CADETS	$11,648	$17,241	Not applicable

Notes:

1/ Effective fiscal year 2005, military personnel services for Foreign Military Sales (FMS) shall be priced using the Composite Rates that already include permanent change of station (PCS) expense and shall no longer use the actual PCS expense for PCS moves to support a FMS case. Effective FY 2006, the military personnel services for FMS shall be priced using the DoD Composite Rate plus the acceleration factor shown in Tab K-1. Reimbursement of the acceleration factor shall be deposited into the Defense Health Program (97*0130). Reimbursement of the per capita normal cost for Medicare-eligible retiree health care (MERHC) accrual shall be deposited into the Miscellaneous Receipts Account 3041. The next update of the DoD FMR Vol. 15 Section 070203 will reflect these change.

2/ The annual DoD composite rate includes the following military personnel appropriation costs: average basic pay plus retired pay accrual, Medicare-eligible retiree health care (MERHC) accrual, basic allowance for housing, basic allowance for subsistence, incentive and special pay, permanent change of station expenses, and miscellaneous pay. **Includes** a per capita normal cost of $5,673 for MERHC accrual -- **see Tab K-1**.

3/ The annual rate billable to Other Federal Agencies recovers additional military related health care costs financed by the Defense Health Program. The annual billable rate includes an acceleration factor of $10,132 for all personnel. **Excludes** per capita normal cost of $5,673 for MERHC accrual -- **see Tab K-1**.

4/ To compute a Daily Rate, apply a factor of .00439. To compute an Hourly Rate, apply a factor of .00055.

5/ Basic pay for these officers is limited to the rate of basic pay for Level II of the Executive Schedule, which currently is $181,587 per year.

Tab K-3

Figure 25. (From "Navy military composite standard pay and reimbursement rates," 2010)

APPENDIX B. HEALTH HAZARD COST

Related cost component	Equation variable	Variable value	Description
All (except death costs)	P_e	See Table 1	Hazard Probability (HP) - Probability of exposure per year, based on the determined hazard probability category
All (except death costs)	S_k	See Table 1	Hazard Severity (HS) factor based on the determined hazard severity category
All (except death costs)	N_s	No. of systems	Number of systems, the total number individual items of materiel, equipment, or weapon systems in Army inventory
All (except death costs)	N_{ps}	No. of persons	Number of persons per system, or crew size for system, or item
All (except death costs)	N_e	Calculated	Total number of people exposed to hazard per year for the systems or items
Clinic costs	C_c	Calculated	Cost of clinic visits
Clinic costs	N_i	Calculated	Number of people injured or ill
Clinic costs	N_v	Calculated	Number of clinic visits
Clinic costs	V_e	0.75	Visit constant as result of exposure. The visit constant (Ve) equals 0.75 and is based on exposure to a health hazard that results in illness or injury. We assumed that if an exposure event occurs, then 75 percent of all persons exposed to the hazard will visit the clinic for an examination to determine whether any injury has occurred.
Clinic costs	I_i	See Table 5	Incidence of injury or illness based on the determined risk level for the individual item of materiel
Clinic costs	N_c	See Table 6	Number of visits by injured or ill personnel based on the determined hazard severity category. The hazard severity category determines the seriousness of the medical outcomes that could occur. As the severity increases, the number of clinic visits increases. For this cost component, based on values selected by a panel of experts, we assigned the number of visits based on the hazard severity category and the potential medical outcomes.
Clinic costs	F_c	$122 per visit	Average fee per clinic visit, based on the average of various types of clinic service visit fees. We found the average fee was $122 per clinic visit.

Figure 26. Equation variables (From "Estimating the health hazard costs," 1998)

Hospitalization costs	**C_h**	**Calculated**	**Cost of hospitalization**
Hospitalization costs	**N_{ph}**	**Calculated**	**Number of persons hospitalized**
Hospitalization costs	**N_h**	**Calculated**	**Number of hospital days**
Hospitalization costs	**I_h**	**See Table 7**	**Incidence of hospitalization based on the determined risk level for the individual item of materiel**
Hospitalization costs	**D_{hd}**	**See Table 8**	**Factor for the average number of days in hospital per person based on historical hospital stay distribution**
Hospitalization costs	**D_{ho}**	**See Table 9**	**Factor for the hospitalization population distribution for average number of days in hospital**
Hospitalization costs	**F_h**	**$1,669 per day**	**Average fee per hospital day. Average cost based on various types of hospital diagnosis-related groups and the classification of the disease. We found the average hospital fee was $1,669 per day.**
Lost time costs	**C_l**	**Calculated**	**Cost of days of lost time**
Lost time costs	**N_{pl}**	**Calculated**	**Number of persons losing time**
Lost time costs	**N_l**	**Calculated**	**Number of lost workdays**
Lost time costs	**I_l**	**See Table 10**	**Incidence of lost time based on the determined risk level for the individual materiel item**
Lost time costs	**D_{ld}**	**See Table 11**	**Factor for the number of lost workdays per person based on historical lost workday distribution**
Lost time costs	**D_{lt}**	**See Table 12**	**Lost time population distribution based on average lost workday distribution**
Lost time costs	**W_d**	**$53.97 per day**	**Average wage per day. We based the average wage per day (Wd) on the salaries and numbers of persons drawing that salary for a selected group of personnel. We determined an average wage to be $53.97 per day.**
Lost time costs	**B_f**	**1.41**	**Wage fringe benefit factor. We assigned the fringe benefit factor (Bf)a value of 1.41. It is a standard factor within the government used for programming personnel budget requirements and is representative of other corporate benefit factors.**
Disability costs	**C_{di}**	**Calculated**	**Cost of disabilities**

Figure 27. Equation variables continued (From "Estimating the health hazard costs," 1998)

Disability costs	N_{pd}	Calculated	Number of persons disabled
Disability costs	I_v	See Table 13	Incidence of VA disability based on the determined risk level for the individual item of materiel, equipment, or weapon system
Disability costs	T_v	0.25	VA disability adjustment factor for delayed disability (5 years/20 years)
Disability costs	D_v	See Table 14	VA disability population factor based on historical rate of disability distribution
Disability costs	B_v	See Table 15	VA disability compensation factor per month per rate of disability
Disability costs	I_t	0.001	Incidence of active-duty temporary disability (1 case/1000 persons)
Disability costs	B_t	$9,242 per person	Active-duty temporary disability compensation per year
Disability costs	I_p	0.011	Incidence of active-duty permanent disability (11 cases/1000 persons)
Disability costs	B_p	$12,864 per person	Active duty permanent disability compensation per year
Rehabilitation costs	C_r	Calculated	Cost of rehabilitation
Rehabilitation costs	N_r	Calculated	Number of rehabilitation cases
Rehabilitation costs	D_r	See Table 16	Eligible VA disability population factor based on rate of disability distribution equal to or greater than 20 percent
Rehabilitation costs	Q_r	0.05	VA rehabilitation qualification factor (5 cases/100 persons eligible)
Rehabilitation costs	B_r	$12,000 per year per person	VA rehabilitation benefit per year per person. We estimated to be $12,000 per year per person. Rehabilitation benefits may vary per person, but we considered $12,000 to be a reasonable estimate. Other benefits may be available for eligible disabled persons, but we did not consider these other benefits.
Death costs	C_{de}	Calculated	Cost of death
Death costs	N_{de}	See Table 17	Number of deaths per year
Death costs	B_{de}	$200,000	Death benefit and expenses

Figure 28. Equation variables continued (From "Estimating the health hazard costs," 1998)

Table 5. Incidence of Illness or Injury (I_i) for System Risk Categories

System risk category	Incidence rate (I_i)
High	0.122
Medium	0.095
Low	0.067

Table 6. Number of Clinic Visits (N_c) for Hazard Severity Categories

Hazard severity category	Number of clinic visits (N_c)
I	5
II	3
III	2
IV	1

Table 7. Incidence of Hospitalization (I_h) for System Risk Categories

System risk category	Hospitalization rate (I_h)
High	0.013
Medium	0.007
Low	0.0005

Table 8.
Factors for Average Number of Days in Hospital (D_{hd}) (days/person)

Length of stay in hospital	Factor (D_{hd})
<2 days	1.0
2–5 days	3.5
6–30 days	18.0
>30 days	30.0

Table 9. Factors for Hospitalization Population Distribution (D_{ho}) by Length of Stay in Hospital for System Risk Categories

System risk category	Length of stay in hospital			
	<2 days	2–5 days	6–30 days	>30 days
High	0.40	0.35	0.17	0.08
Medium	0.40	0.36	0.18	0.06
Low	0.42	0.37	0.20	0.02

Figure 29. Health Hazard Cost Method Criteria (From “Estimating the health hazard costs,” 1998)

Table 10. Incidence of Lost Time (I_l) for System Risk Categories

System risk category	Lost time rate (I_l)
High	0.055
Medium	0.054
Low	0.028

Table 11.
Factors for Average Number of Days of Lost Time (D_{ld}) (days/person)

Number days of lost time	Factor (D_{ld})
<2 days	1.0
2–5 days	3.5
6–30 days	18.0
>30 days	30.0

Table 12. Factors for Lost Time Population Distribution (D_{lt}) by Days of Lost Time for System Risk Categories

System risk category	Lost time			
	<2 days	2–5 days	6–30 days	>30 days
High	0.22	0.30	0.29	0.20
Medium	0.20	0.33	0.31	0.16
Low	0.15	0.43	0.38	0.04

Table 13. Incidence of VA Disability (I_v) for System Risk Categories

System risk category	VA disability factor (I_v)
High	0.032
Medium	0.012
Low	0.00005

Table 14. Factors for Disability Population Distribution (D_v) by Degree of Disability for System Risk Categories

System risk category	Degree of disability			
	10%	20%–50%	60%–90%	100%
High	0.44	0.42	0.10	0.04
Medium	0.44	0.44	0.09	0.03
Low	0.43	0.48	0.08	0.01

Figure 30. Health Hazard Cost Method Criteria (From "Estimating the health hazard cost," 1998)

Table 15. VA Disability Compensation Factors (B_r) by Degree of Disability (dollars/month/person)

Degree of disability	VA disability compensation factor (B_r)
10%	$91.00
20%–50%	$340.25
60%–90%	$915.50
100%	$1,865.00

Table 16. Eligible VA Disability Population Distribution Factors (D_r) by Degree of Disability for System Risk Categories

	Degree of disability			
System risk category	10%	20%–50%	60%–90%	100%
High	0.0	0.42	0.10	0.04
Medium	0.0	0.44	0.09	0.03
Low	0.0	0.48	0.08	0.01

Table 17. Number of Deaths (N_{de}) for Hazard Severity Categories

Hazard severity category	Number of deaths (N_{de})
I	1
II	0
III	0
IV	0

Table 18. Health Hazards and Associated Risk Indices for System X

Hazard category	Hazard	Risk assessment code (RAC)	Hazard severity category	Hazard probability
Chemical substances	Weapons combustion products	1	I	A
Chemical substances	Fire extinguishing agents	2	II	C
Chemical substances	Carbon dioxide	3	II	D
Acoustical energy	Impulse noise	2	II	C
Acoustical energy	Steady-state noise	2	II	C
Temperature extremes	Cold stress	2	II	C
Temperature extremes	Heat stress	2	II	C
Oxygen deficiency	Oxygen deficiency (ventilation)	2	II	C
Radiation energy	Nonionizing radiation	2	II	C
Radiation energy	Ionizing radiation	4	II	E

Figure 31. Health Hazard Cost Method Criteria (From "Estimating the health hazard cost," 1998)

APPENDIX C. LIFE CYCLE PHASE HSI ACTIVITIES

Event	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
A.	Provide HSI activity input during Capabilities Based Assessment for ICD	*DOTMLPF Analysis, Analysis of Materiel and Non-Materiel, and lessons	Pre-Materiel Solution Analysis	All Domains (Integrated Assessments)	Documentation to match life cycle needs (Breadth and depth of required
B.	Provide HSI input into HSIP for the System Engineering Plan (SEP)	*Appoint HSI Lead. **Work with PM to determine if standalone	Pre-Materiel Solution Analysis	All Domains (Integrated Assessments)	Complexity, Maintenance Concept, Manning, Mission, Operational Capability,
C.	Provide a total system analysis based on functional relationship	*Analyze and assess trade space, related constraints/requirements	Pre-Materiel Solution Analysis	All Domains (Integrated Assessments)	Complexity, Maintenance Concept, Manning, Mission, Operational Capability,
D	Provide HSI considerations into AoA Study plan	*Identify AoA manpower estimating tools, analysis techniques.	Pre-Materiel Solution Analysis	All Domains (Integrated Assessments)	General Drivers: Complexity, Maintenance Concept, Manning, Mission,
E.	Provide input into ESOH integration Strategy.	*Define HSI roles and activities for Environmental, Safety and Occupational	Pre-Materiel Solution Analysis	All Domains (Integrated Assessments)	Complexity, Maintenance Concept, Manning, Mission, Operational Capability,
F.	Provide a HSI assessment based on best available solution description (in	*Infrom Sustainment and affect design the design and support plans that	Pre-Materiel Solution Analysis	All Domains (Integrated Assessments)	Manning
E.	Perform a HSI analysis of legacy systems with respect to each domain and	*Review the legacy system's Post Implementation Review	Materiel Solution Analysis	All Domains (Integrated Assessments)	Cognitive Workload, Complexity, Initial Training (Instructor & Key
F.	Contribute to assessment and development of system concepts /Materiel	*Consider personnel alternatives based on AoA. **Determine appropriate	Materiel Solution Analysis	All Domains (Integrated Assessments)	Initial Training (Instructor & Key Personnel), Initial Training (New Equipment at
G.	Assist in development of cost estimate based on anticipated HFE,	*Provide input to Manpower Estimate Reports	Materiel Solution Analysis	All Domains (Integrated Assessments)	Initial Training (Instructor & Key Personnel), Maintenance Requirement,
H.	Conduct Mission Task Analysis.	*Define the human performance characteristics of the user population.	Materiel Solution Analysis	All Domains (Integrated Assessments)	Cognitive Workload, Complexity, Criticality of Task, Difficulty of Task,

Figure 32. Materiel Solution Analysis HSI Activities

Event	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
I.	Conduct Initial Top Down Requirements Analysis.	*Participate in an IPT and provide preliminary input into Manpower and	Materiel Solution Analysis	Manpower	Cognitive Workload, Frequency of Task, Manning, Mission,
J.	Assist in performance of Manpower /Personnel alternatives and concept	*Use findings from mission task analysis and other personnel assessments.	Materiel Solution Analysis	Personnel, Manpower	Operational Capability, Personnel experience/continuity
K.	Identify manning needs, manpower lessons learned, and high drivers from	*Establish preliminary manpower thresholds and objectives.	Materiel Solution Analysis	Manpower, Personnel	Complexity, Maintenance Requirement, Manning, Mission, Operational
L.	Assist in linear modeling and studies analysis of system approach	*Assist in Effectiveness Analysis Working Group (EAWG).	Materiel Solution Analysis	Manpower, HFE, Training	Manning, Modeling&Simulation, Operational Capability,
M.	Conduct Manpower/Training assessments to determine	*Conduct preliminary learning performance and solution analysis to justify	Materiel Solution Analysis	Training, Personnel	Cognitive Workload, Initial Training (Instructor & Key Personnel), Initial Training
N.	Assist in deriving Systematic Prediction of Conditions through Initial	*Review draft /final assessments and associated costs.	Materiel Solution Analysis	ESOH	Criticality of Task, Frequency of Task, Manning, Mission, Physical
O.	Participate in AoA assessments.	*Optimize MPT for AoA. **Identify capability gaps in Manpower reduction.	Materiel Solution Analysis	All Domains (Integrated Assessments)	Cognitive Workload, Complexity, Maintenance Requirement, Manning,
P.	Define concept capabilities and requirements.	*Determine HFE and Human performance requirements.	Materiel Solution Analysis	HFE, Manpower, Personnel	Cognitive Workload, Complexity, Frequency of Task, Maintenance
Q.	Provide HSI input into Technology Development Strategy.	*Provide preliminary inputs into MDA cost estimates for TD phase to support the	Materiel Solution Analysis	HFE, Manpower, Personnel, Training	Cognitive Workload, Complexity, Criticality of Task, Difficulty of Task,
R.	Provide HSI Input into Life-cycle Sustainment Plan.	*Provide preliminary considerations into Habitability, Training, and	Materiel Solution Analysis	All Domains (Integrated Assessments)	Demilitarization and Disposal, Migration complexity (Influence of
S.	Provide HSI input into Support System Engineering Technical	*Provide input into the Initial Technical Review (ITR) and Alternative System Review	Materiel Solution Analysis	HFE, Manpower, Training	Complexity, Manning, Mission, Requirements understanding (Subjective

Figure 33. Materiel Solution Analysis HSI Activities (continued)

EVENT	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
GUIDE	Review all the inputs to the Technology Development Phase	1.0 Update HSI domain effects. 1.1 Review and update	Technology Development	All Domains (integrated assessment)	Manning, tools, simulation, software, analyses, training,
A.	Determine the need for an HSI IPT or a Working Group.	*Review outputs from user CONOPs developments, needs	Technology Development	All as appropriate to the solution	Manning, tools, simulation, software, analyses, training,
B.	Establish a HSI IPT or Working Group - consistent with the size	*Identify candidate participants / team members to participate	Technology Development	All Domains (integrated assessment)	Manning, Personnel experience/continuity (Subjective
GUIDE	Throughout the next 5 steps C-G conduct trade offs and support	* Participate in AoA to ensure that HSI considerations have	Technology Development	All Domains (integrated assessment)	
C.	Determine all relevant critical operational issues and determine	* Interpret User Needs, Analyze Operational Capabilities &	Technology Development	HFE, Manpower, Training,	Maintenance Concept, Maintenance Requirement, Mission,
D. Callout	Develop system performance (&constraints)	* Ensure HSI criteria are traceable back to defined system	Technology Development	All Domains (integrated assessment)	Manning, travel.
E. Callout	Develop functional definitions for Enabling/Critical	* Define HSI criteria for weapon system, support, equipment,	Technology Development	All Domains (integrated assessment)	Manning, tools, evaluations, analyses.
F. Callout	Decompose functional definitions into Critical Component Definition	* Update system HSI criteria. * Assess HSI impacts	Technology Development	All Domains (integrated assessment)	Manning, simulation, tools, evaluations.
G.	Identify HSI technical risks and mitigation strategies for	*Identify detailed administrative processes for HSI	Technology Development	All Domains (integrated assessment)	Difficulty of Task, Maintenance Requirement, Physical

Figure 34. Technology Development Phase HSI Activities

EVENT	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
GUIDE	Throughout the next 7 Steps H-O conduct trades that are spread	* Conduct trade studies on threshold and objective levels of	Technology Development	All Domains (integrated assessment)	
H.	Demonstrate enabling/critical technology	* Integrate evaluations of critical technologies across all functional	Technology Development	All Domains (integrated assessment)	Maintenance Concept, Manning, Mission, Operational Capability,
I.	Provide integrated HSI assessment methodology for technology down	*Define relevant criteria across the HSI domains and for overall integration	Technology Development	Human Factors Engineering (HFE)	Complexity, Manning, Modeling&Simulation, Testing Type-campaign or force-
J.	Refine and update requirements.	*Update HFE for HMI, HCI, Workspace, Human Performance	Technology Development	HFE, Manpower, Personnel,	Manning
K.	Assist in technology selection.	*Address all relevant requirements that have HSI implications.	Technology Development	All Domains (integrated assessment)	Manning, Specialty Personnel, Training Analysis and Design
L.	Perform analysis and recommendations for system technology	*Perform Operational Workflow Analysis. *Perform Manpower,	Technology Development	HFE, Manpower, Personnel,	Cognitive Workload, Criticality of Task, Difficulty of Task,
M.	Assist in development of System Functional Specs & Verification	*Perform HSI Functional Allocation Analysis.	Technology Development	HFE, Manpower, Personnel,	Cognitive Workload, Manning, Mission, Operational Capability,
N.	Participation in Integrated Test Team (ITT) and evaluation or	*Determine scope of Safety and Occupational Health	Technology Development	Environment, HFE, Manpower,	Complexity, Manning, Modeling&Simulation, Testing Type-
O.	Develop T&E / V&V program plans inclusive of all the	*Develop HSI Methods, Metrics, Analysis and Tools.	Technology Development	HFE	Complexity, Manning, Mission, Modeling&Simulation,

Figure 35. Technology Development Phase HSI Activities (continued)

EVENT	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
Guide	Throughout the next 7 Steps P-S conduct trades that are spread	* Conduct trade studies on threshold and objective levels of	Technology Development	All Domains (integrated assessment)	Manning, modeling / simulation, analyses, trade studies.
P. Callout	Demonstrate enabling/critical technology	* Integrate evaluations of critical technologies across all functional	Technology Development	All Domains (integrated assessment)	Manning, travel, tools.
Q. Callout	Demonstrate system & prototype functionality versus plan.	* Evaluate critical technologies from an HSI perspective	Technology Development	All Domains (integrated assessment)	Manning
R. Callout	Demo/Model integrated system versus performance	* Evaluate critical technologies from an HSI perspective.	Technology Development	All Domains (integrated assessment)	Manning, models / simulation
S. Callout	Demonstrate & validate System & Technology Maturity	* Ensure applicable HSI elements are embedded in the	Technology Development	All Domains (integrated assessment)	Manning
GUIDE	Insure the production and completion of inputs to the following	1.0 Incorporate domain considerations into baseline parameters	Technology Development	All Domains (integrated assessment)	Manning, tools, simulation, software, analyses, training,
T.	Review and provide input into Preliminary design and allocation	*Provide HSI inputs into all relevant areas (e.g. systems safety,	Technology Development	Environment, HFE, Occupational	Manning, tools, simulation, software, analyses, training,
U.	Provide HSI input into the Capability Development	*Provide design considerations for environmental facts,	Technology Development	Environment, HFE, Manpower,	Manning, Mission
V.	Provide input into the Acquisition Strategy for goals, objectives and	*Provide an outline methodology to: **Determine	Technology Development	HFE, Manpower, Personnel,	Manning, Mission, Operational Capability

Figure 36. Technology Development Phase HSI Activities (continued)

EVENT	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
W.	Provide input into Acquisition Program Baseline (APBs).	*Provide input for KPP, KSA, Threshold and Objective values and requirements considerations. *Operationally define performance parameters, measures of	Technology Development	HFE, Manpower, Personnel	Level of service requirements (Subjective difficulty of satisfying the key performance Parameters), Manning,
X.	Incorporate requirement for contractor generated HSIP(s) and associated source selection criteria in Request for Proposals (RFPs).	*Review RFP language, CDRLs and DIDs for HSI Planning activities for each human performance.	Technology Development	All Domains (integrated assessment)	Manning
Y.	Conduct formal development of human-centered source selection criteria for RFPs at Milestone (MS) A.	*Conduct HSI review of source selection criteria for developmental RFPs. **Review all source selection criteria for HSI relevance.	Technology Development	All Domains (integrated assessment)	Complexity, Maintenance Requirement, Manning, Mission, Platforms, Specialty Personnel
Z.	Apply analysis in findings to Test and Evaluation Strategy (TES), LCMP and TEMP	*Conduct Special analysis to update thresholds, objectives, and evolving criteria for DT&E and eventually OT&E. *Update HSI test plans as necessary	Technology Development	All Domains (integrated assessment)	Manning
AA.	Provide input into System Engineering Review Process (SRR).	*Provide input into SRR for implication of humans into system. SFR for operation level functional requirements as IPT member.	Technology Development	HFE, Manpower, Survivability	Complexity, Maintenance Requirement, Manning, Mission, Operational Capability, Personnel/team capability
BB	Provide input into System Engineering Review Process (SFR)	* Address HSI requirements in the system functional baseline and in conjunction with the lower-level performance requirements.	Technology Development	All Domains (integrated assessment)	Manning
CC	Provide input into System Engineering Review Process (PDR)	* Ensure domain-specific performance requirements are included in the preliminary design. * Review subsystem requirements to address HSI issues	Technology Development	All Domains (integrated assessment)	Manning, Travel

Figure 37. Technology Development Phase HSI Activities (continued)

Event	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
A.	Provide HSI input to the TEMP.	*Incorporate use of HSI IPT (Evaluation Plans): Identify	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Complexity, Manning, Mission,
B.	Finalize HSI requirements by obtaining	*Determine Assessment methods;	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Complexity, Manning, Mission, Modeling&Simulati
C.	Assist in development of detailed design	*Provide guidance for supporting development of	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Complexity, Frequency of Task, Mission,
D.	Assess detailed system designs to ensure that they	*Validate manpower estimate basis	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Manning, Mission, Operational Capability,
E.	Participate in Prototypes/Test Materials	Interactively develop and review prototypes,	E&MD: Integrated System Design	Human Factors Engineering	Cognitive Workload, Complexity,
F.	Evaluate Prototypes (or Test Materials) for HSI criteria .	Perform heuristic evaluations, Cognitive	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Cognitive Workload, Complexity,
G.	Participate in design demonstrations (to include	*Verify detailed system designs. *Evaluate initial	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Mission, Operational Capability,
H.	Evaluate HSI criteria for the system during component /	*Complete data collection during DT&E and OT&E for	E&MD: Integrated System Design	All Domains (Integrated Assessment)	Complexity, Platforms, Testing Type-campaign or
I.	Perform HSI evaluation on system	*Determine impact on human performance and	E&MD:System Capability & Manufacturing	All Domains (Integrated Assessment)	Complexity, Modeling&Simulati on, Personnel/team

Figure 38. Engineering and Manufacturing Development Phase HSI Activities

Event	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
J.	Assist in Development of Test Plans for	*Develop test plans for human performance	E&MD:System Capability & Manufacturing	Human Factors Engineering	Occupational Training, Testing Type-campaign or
K.	Participate in HSI Test events.	*Perform analysis and reporting functions related to	E&MD:System Capability & Manufacturing	All Domains (Integrated Assessment	Modeling&Simulation, Operational Capability, Testing
L.	Participate in ECP development.	*Generate and review HFE related ECPs for human	E&MD:System Capability & Manufacturing	Human Factors Engineering	Manning
M.	Provide HSI updates to Acquisition Strategy and APB.	*Ensure continued emphasis on HSI requirements met	E&MD:System Capability & Manufacturing	Manpower Personnel, Training	Manning
N.	Provide HSI input into Capability Production	*Provide input to CPD based on lessons learned	E&MD:System Capability & Manufacturing	Environment, Habitability	Manning
O.	Provide HSI input into Technical Reviews and	*Contribute HSI-related entry and exit criteria for	E&MD:System Capability & Manufacturing	Human Factors Engineering	Manning, Operational Capability,
P.	Provide HSI input for Error and Fault analysis.	*Examine workload levels at micro-, meso-, and macro-	E&MD:System Capability & Manufacturing	Human Factors Engineering	Complexity, Criticality of Task, Difficulty of Task,

Figure 39. Engineering and Manufacturing Development Phase HSI Activities (continued)

Event	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
A.	HSI Planning and Management	*As member of Integrated Product Team, review, update and trade-off prior	Production and Deployment	All Domains (Integrated)	Manning, Requirements understanding, Level of Service Requirements, Time
B.	Review and develop HFE installation Criteria.	*Consider human performance workload and safety. *Identify gaps or potential	Production and Deployment	HFE	Complexity, Level of service requirements (Subjective difficulty of satisfying the key
C.	Verify HSI requirements for installation criteria.	*Assist in HSI verification of system installation requirements	Production and Deployment	All Domains (Integrated)	Cognitive Workload, Level of service requirements (Subjective difficulty of
D.	Assist in T&E HSI analyses of system design and installation (including LRIP deficiencies).	*Document HSI-related system performance issues (i.e., PTRs).	Production and Deployment	All Domains (Integrated)	Cognitive Workload, Complexity, Manning, Migration complexity (Influence
E.	Assist in T&E analyses of system design and installation (including LRIP deficiencies),	*Evaluate system components having an impact on human performance and safety.	Production and Deployment	Human Factors Engineering	Complexity, Level of service requirements (Subjective difficulty of satisfying the key
F.	T&E support and participation (IOT&E).	*Develop user assessment for IOT&E **Develop user-centric	Production and Deployment	All Domains (Integrated)	Complexity, Level of service requirements (Subjective difficulty of satisfying the key
G.	T&E support and participation (LFT&E) (separated from previous	*Define and test appropriate metrics (identified in JCIDS (CDD and CPD), RFP, etc).	Production and Deployment	All Domains (Integrated)	Manning; Testing Type-Campaign or force-level, Documentation to match Life
H.	T&E support and participation (FOT&E) (separated from previous	*Develop user-centric assessment to support FOT&E.	Production and Deployment	All Domains (Integrated)	Cognitive Workload, Complexity, Manning, Migration complexity (Influence

Figure 40. Production and Development Phase HSI Activities

Event	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost_Drivers
I.	Review OPTEVFOR reports and discuss HSI trade-offs.	*Participate in an IPT and coordinate with stakeholder. *Verify and validate final HFE related production items.	Production and Deployment	Human Factors Engineering	Manning, Testing type, Requirements Understanding, Documentation to match life cycle needs, Multisite coordination
J.	Document and analyze post deployment lessons learned.	*Collect and analyze user feedback and service use data from post-deployment system. **Analyses of LRIP system performance	Production and Deployment	Human Factors Engineering	Manning, Documentation to match life cycle needs, Requirements understanding, Level of service requirements, Testing, Time constraint for System Development
K.	Provide input into review process for P&D Phase. (OTRR,AOTR,PCA; *overview and involved participation)	*Provide input for assurance of operational capabilities and effectiveness (may delay FRP) prior to IOT&E (OTRR) At demonstration (AOTR).	Production and Deployment	Human Factors Engineering, Survivability, Training	Complexity, Manning, Mission, Operational Capability, Personnel/team capability (Subjective assessment of the team's intellectual capability), Platforms; Testing
L.	Update Manpower/Personnel requirements for system design and LCMP.	*Perform analysis and reporting on Manpower related test events, data collected, and findings. *Revise the MER to reflect system design.	Production and Deployment	Manpower, Personnel	Complexity, Manning, Mission, Platforms, Specialty Personnel Initial Training (Instructor and Key Personnel), Mission, Testing Type-
M.	Update Training systems requirements for system design and LCMP.	*Assess training solutions during initial system component demonstrations. *Refine training solutions based on findings from initial system component	Production and Deployment	Manpower, Personnel, Training	Initial Training (Instructor & Key Personnel), Initial Training (New Equipment at system fielding), Manning, Mission, Occupational Training, Training Analysis
N.	Assist with System Hazard Analysis (SHA)and Operating and Support Hazard Analysis (O&SHA) and System Safety Analysis (SSA).	*Participate in system test events. **Perform analyses and reporting on Safety and Occupational Health (Health Hazards) related test events, data collected, and	Production and Deployment	HFE, Habitability, ESOH (Health Hazards, Systems Safety)	Manning, Testing Type-system simulation and stimulation, Specialty Personnel

Figure 41. Production and Development Phase HSI Activities (continued)

	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	Cost Drivers
A.	HSI Planning and Management	*Provide updates to the HSI Plan. *Provide Status reports and	Operation & Support	All Domains (Integrated Assessment)	Manning, Requirements understanding, Documentation to match life
B.	Provide follow-on Test and Evaluation support.	*Collect and analyze user feedback and service use data from the post-deployed	Operation & Support	Human Factor Engineering	Cognitive Workload, Complexity, Criticality of Task, Difficulty of Task,
C.	Provide analysis for HFE FOC support and logistics/sustainment	*Provide HFE based recommendations for system modernization and	Operation & Support	Human Factor Engineering Habitibility	Cognitive Workload, Complexity, Criticality of Task, Difficulty of Task,
D.	Provide recommendations for HFE FOC support and logistics/sustainment	*Provide HFE based recommendations for system modernization and	Operation & Support	All Domains (Integrated Assessment)	Complexity, Maintenance concept, Maintenance Requirement,
E.	Provide Training FOC support and logistics/sustainment	*Transition post-fielding Training Evaluation Analysis (PFTEA).	Operation & Support	Training	Complexity, Manning, Modeling & Simulation, Difficulty of Task, Criticality
F.	Provide Manpower/Personnel FOC support and	*Verify measure of effectiveness survey. *Verify system installations	Operation & Support	Manpower, Personnel	Manning (Maintenance concept, Requirements understanding, Migration
G.	Analyze and prototype post-product improvements for the next inremental build.	*Assess Human-Machine interfaces, Human-Computer Interfaces,	Operation & Support	Human Factor Engineering	Cognitive Workload, Complexity, Criticality of Task, Difficulty of Task,
H.	Provide input for sustainment of operational readiness and safety of	*Provide modeling and simulation process or improvement during FRP	Operation & Support	Human Factor Engineering, Manpower,	Manning, Modeling&Simulation, Testing Type-campaign or
I.	Provide testing and verification of follow-on T&E processes.	Verify suitability and effectiveness for system. *(Include availability,	Operation & Support	Human Factor Engineering, Manpower,	Manning;Maintenance concept, Requirements understanding, Physial
J.	Provide FOC support and logistics/sustainment transistion and Operation	*Provide updates for ESOH strategy and PESHE in conjuction with SE	Operation & Support	Environment, Occupational Health, System	Manning; Requirements understanding, Speciality Personnel, Maintenance
K.	Provide input into O&S review processes (ISR)	*Provide measurable assessments for risk, readiness, technical status	Operation & Support	Human Factor Engineering, Manpower,	Manning (Modeling & Simulation, Mission, Migration Complexity,

Figure 42. Operation and Support HSI Activities

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APPENDIX D. REVIEW INSTRUCTIONS

(Note: For THESIS-VIEW ONLY of Review Instructions. For examples, refer to Figures 42 and 43, and Tables 27 and 28)

Human System Integration Activity SME Review

Background:

Research is underway at the Naval Postgraduate School to facilitate Human System Integration (HSI) cost estimation (CE) in the Analysis of Alternative (AoA) portion of the Defense Acquisition process. The goal is to develop a database of HSI CE activities that spans the entire Acquisition life cycle and supports the cost estimation processes.

You have been identified as a Subject Matter Expert (SME) in HSI, an HSI domain or cost estimation. We request you review a selected (assigned) portion of the database and provide us feedback. Any questions related to this request can be directed to LT Deborah Sindall, USN at dasindal@nps.edu and by telephone 571.830.4971.

Instructions to the Reviewer: (2 Parts)

1. **Column Headings for Access Database.**

   Review the columns that are proposed for the Access database. Refer to Excel file Tab 1 (Column Descriptions) or Table 1 on Page 4 of these instructions for a list of columns and descriptions.

   a. On Excel file Tab 1 (Column C), provide comments regarding additions, deletion or modification of columns for the database. An example is provided on Page 3 of these instructions. **Note: Data are not system specific.**

   b. If a column should be added, add the item to the bottom of the list.

2. **HSI Activities in Defense Acquisition Phases.**

   For selected rows and columns on Excel file (Tab 2, HSI Activity), review the content to ensure it is appropriate for cost estimation of HSI activities in AoA. A blank row for each activity has been provided for your comments. If no correction is needed, please indicate this in the row provided. Examples of comments and corrections have been provided on Page 3. **Note: You will be given one or two phase activities on the Excel file for review.**

   a. For Column A (HSI Activity) and B (HSI Sub Activity):

      i. For each row, determine if this is a major HSI activity. If so, is the activity worded properly? If incorrect, provide a recommendation in the comment row.

ii. Determine if the Sub Activity is appropriate for the Major HSI activity. If incorrect, recommend additions, deletions or modifications in the comment row.

b. For Column C, Acquisition Phase:

i. Determine whether the acquisition phase is correct for the activity. If activity occurs during another phase, indicate appropriate phase in comment row below activity.

c. For Column D (HSI Domain (*Impacted))*:

i. Determine if listed domains are affected by HSI activity and sub activity. If incorrect, recommend additions or deletions of domains in the comment row.

d. For Column E (% Effort):

i. On a 100% scale, estimate to the best of our ability, what percentage of man hours is spent on this activity for a generic ACAT I system. Your percentages should add to 100% **for each phase**. (We realize that HSI efforts will vary widely depending on the type of system. This column represents an initial attempt at determining level of effort required for HSI practitioners.)

e. For Column F (Cost Drivers):

i. Review the list of Cost Drivers on Excel file Tab 3 (Cost Drivers). **Also available on Page 5 of these instructions.**

ii. Determine if listed potential cost drivers are appropriate for activity listed. If drivers listed are incorrect, recommend additions or deletions for the activity in the comment row. If a cost driver is not listed but should be included, please provide the driver in comment row.

f. **For Missing Activities**:

i. If an HSI activity or sub-activity has been left out of the database, please add it to the bottom of the activity list. Fill out as much information for the columns as possible to ensure the activity it is represented appropriately.

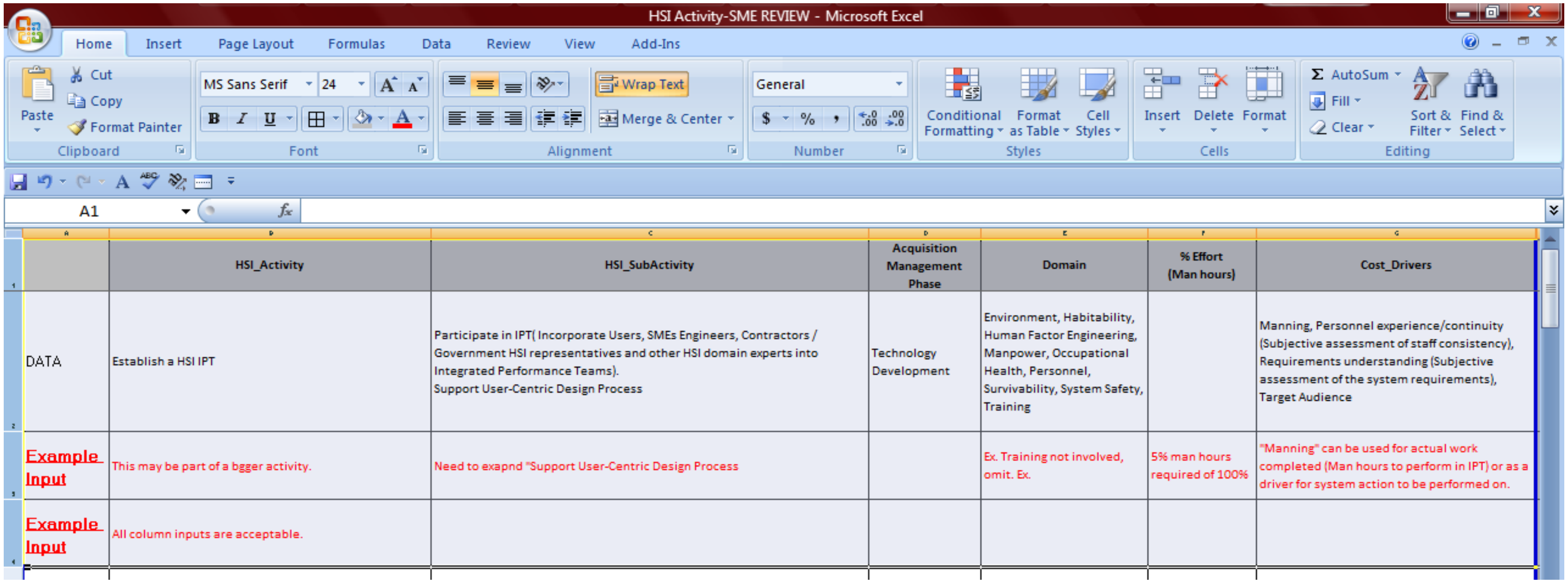
3. Save the document using Excel (97-2003) compatible file type using "samefilename_yourinitials.xls" format. Please send to dasindal@nps.edu no later than 31 Aug 2010. If more time is needed, please e-mail with request.

Sources of HSI Data:

HSI CE activity development was determined through analysis of current instruction, guidance, integrated frameworks and past HSI cost studies. Please see Page 6 of these instructions for a list of resources.

WBS Cost Element	Numeric Code for organization of Activities based on Specific Program Work Breakdown Cost Structure (Procurement, O&S, O&M, RDT&E, Spares)	Example Comment: WBS structure is generic and will be taylored down for specific systems.
Acquisition Phase	6 Phases total: Pre-Material Solution Analysis (Pre-MSA); Material Solution Analysis (MSA), Technology Development Phase (TD); Engineering & Manufacturing Development Phase: Integrated System Design, System Capability and Manufacturing Process Demonstration (EMD); Production & Deployment (PD); Operation and Support (O&S)	

Figure 43. Column Heading Description Example -Q1 (From Review Instructions Page 4)



	HSI_Activity	HSI_SubActivity	Acquisition Management Phase	Domain	% Effort (Man hours)	Cost_Drivers
DATA	Establish a HSI IPT	Participate in IPT(Incorporate Users, SMEs Engineers, Contractors / Government HSI representatives and other HSI domain experts into Integrated Performance Teams). Support User-Centric Design Process	Technology Development	Environment, Habitability, Human Factor Engineering, Manpower, Occupational Health, Personnel, Survivability, System Safety, Training		Manning, Personnel experience/continuity (Subjective assessment of staff consistency), Requirements understanding (Subjective assessment of the system requirements), Target Audience
Example Input	This may be part of a bgger activity.	Need to exapnd "Support User-Centric Design Process		Ex. Training not involved, omit. Ex.	5% man hours required of 100%	"Manning" can be used for actual work completed (Man hours to perform in IPT) or as a driver for system action to be performed on.
Example Input	All column inputs are acceptable.					

Figure 44. HSI Activity Review Example -Q2 (From Review Instructions Page 3)

Table 27. SME Review Potential Column Names and Descriptions for HSI Activity Database Development (From Review Instructions, Page 4)

Column Name	Description
WBS Cost Element	Numeric Code for organization of Activities based on Specific Program Work Breakdown Cost Structure (Procurement, O&S, O&M, RDT&E, Spares)
Acquisition Phase	7 Phases total: Pre-Material Solution Analysis; Material Solution Analysis, Technology Development Phase; Engineering & Manufacturing Development Phase: Integrated System Design, System Capability and Manufacturing Process Demonstration; Production & Deployment; Operation and Support
Event Category	Organization of Phase activities based on IDTA&L Defense Interactive Framework (JCIDS Joint Capabilities Integration and Development System, Information Technology (IT) & National Security (NSS), Earned Value Management (EVM), Oversight & Review, Contracting, Major Products, Life Cycle Logistics/Sustainment, Technical, Cost
HSI Activity	HSI practitioners expected contribution to acquisition process.
HSI Sub Activity	Detail level or subset of HSI Activity
% Effort	On a scale of 1-100% for each phase, the level of HSI practitioner effort contributed in program management. For Example: Activity One" Provide HSI activity input during Capabilities Based Assessment for ICD and CDD", HSI activity is only 3% of man-hour effort for WEAPONS (TRACKED VEH) PROCUREMENT (2033 - WTCV).
HSI Domain (impacted)	HSI domain affected by the activity being performed. (practitioner, IPT, or domain involvement) Environment, Habitability, Human Factor Engineering, Manpower, Occupational Health, Personnel, Survivability, System Safety, Training.
System Type	Type of system /program that HSI activities will be performed on (i.e. aviation, ship building, weapon system, etc).
Critical Issues	Operation Effectiveness or Technical Issues that will affect Test and Evaluation Processes (i.e. Survivability, Reliability)
Measures of Effectiveness	Measure designed to correspond to accomplishment of mission objectives and achievement of desired results.
Measure of Performance / Suitability	MOP: Measure of a system's performance expressed as speed, payload, range, time on station, frequency, or other distinctly quantifiable performance features. MOS: Measure of an item's ability to be supported in its intended operational environment. MOSs typically relates to readiness or operational availability, and hence reliability, maintainability, and the item's support structure.
Cost Drivers	An element that impacts the cost of an activity (i.e. Manning, Cognitive Workload, Specialty Personnel) * Will be used in combination with MOE/MOP to develop potential Cost Element and Cost Element Relationships for Database Development*
Benefit	It defines a solution aimed at achieving specific organizational objectives by quantifying the potential financial impacts and other business benefits such as: Savings and/or cost avoidance, Revenue enhancements and/or cash-flow improvements, Performance improvements. Are listed as quantifiable/non-quantifiable. Used to develop Cost Element Relationships.
Cost Estimation Type	*Program Office Estimate. *Component Cost Estimate. *Independent Cost Estimate: * Life-cycle cost estimate. *Total Ownership CE: estimate consists of the elements of life-cycle cost plus some infrastructure and business process costs not necessarily attributable to a program. *Rough Order of Magnitude. *Independent Cost Assessment, Independent Government Cost Estimate.
Cost Estimation Relationships	complex equations with a number of independent variables. Or Cost Factors (single independent variable). Ratios or percentages use in cost estimation (i.e. parameteric cost estimation methods).
Impact	Potential Impact of benefit provided. Used to determine Trade-off. Database will include Benefit Library with Benefit ID, Description, and Category (quantifiable, non-quantifiable)
Trade-off	Potentially weighted domains or benefits that are used for cost over another. Baed on program/system
Comments	Process, Detail or integration notes relevant to HSI Activity or Sub Activity.
Target Documents	Source or projected document for which HSI activity occurs (Ex: Contractor Cost Data Reports Cost Performance Reports, Selected Acquisition Reports, Recent Defense Acquisition Executive Summaries, Unit Cost Reports, Manpower Estimate Reports, HSIP, TEMP, SEP, ITR etc.
References	Resources for further database user information.

Table 28. SME Review Potential Cost Drivers (from Review Instructions, Page 5)

Cognitive Workload
Complexity
Criticality of Task
Difficulty of Task
Documentation to match life cycle needs (Breadth and depth of required documentation)
Frequency of Task
Initial Training (Instructor & Key Personnel)
Initial Training (New Equipment at system fielding)
Level of service requirements (Subjective difficulty of satisfying the key performance Parameters)
Maintenance Concept
Maintenance Requirement
Manning
Migration complexity (Influence of legacy system (if applicable))
Mission
Modeling & Simulation
Multisite coordination (Location of stakeholders and coordination barriers)
Occupational Training
Operational Capability
Personnel experience/continuity (Subjective assessment of staff consistency)
Personnel/team capability (Subjective assessment of the team's intellectual capabilty)
Physical Workload
Platforms (ships, aircraft, weapon systems, etc)
Process capability (CMMI level or equivalent rating)
Requirements understanding (Subjective assessment of the system requirements)
Size
SLOC
Specialty Personnel
Stakeholder team cohesion (Subjective assessment of all stakeholders)
Target Audience
Technology risk (Maturity, readiness, and obsolescence of technology)
Time Constraint for System Development
Tool support (Subjective assessment of SE tools)
Testing Type-detailed component testing Testing Type-subsystem integration Testing Type-system simulation and stimulation Testing Type-campaign or force-level (system of systems).
Type
Unit/Sustainment Field Training
Warranties

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